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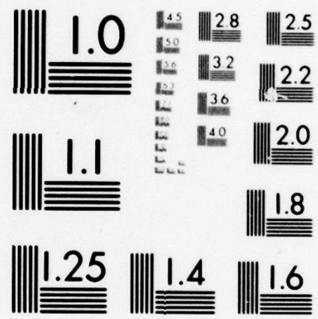

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RESEARCH NEEDS RELATING TO AIRCREW VISUAL REQUIREMENTS

Proceedings of the 1979 Symposium held at the National Academy of Sciences, Washington, D.C.

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Washington, D.C. 20361

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The workshop on Research Needs Relating to Aircrew Visual Requirements was organized to provide those who are familiar with the literature on vision research and who are themselves researchers, insight into the operational requirements confronting aircrew personnel, and vice versa. This volume includes both the prepared texts of the formal presentations and the edited discussions which occurred during the workshop. In addition, the Verbatim texts of the first three papers are presented because of the valuable additional information contained therein.

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PREFACE

The Workshop on Research Needs Relating to Aircrew Visual Requirements was sponsored by the Naval Air Systems Command, and was organized and coordinated by the Naval Air Development Center Vision Laboratory. The workshop was held, with the cooperation of the National Academy of Sciences - National Research Council Committee on Vision, at the National Academy of Sciences in Washington, D. C. on April 11, 1979.

The Workshop was organized to provide those who are familiar with the literature on vision research and who are themselves researchers, insight in to the operational requirements confronting aircrew personnel, and vice versa. The morning session of the workshop was devoted to discussions of the operational aspects of aircrew visual performance and the afternoon session was devoted to current research and discussions of projected research studies and needs.

The proceedings reported in this volume include both the prepared texts of the formal presentations and the edited discussions which occurred during the workshop. In addition, the Verbatim texts of the first three papers are presented. The decision was made to treat the first three papers in this manner because the verbatim presentation included material which was valuable in providing the operational insights which were sought, and which were not covered in the prepared texts.

The verbatim report of the proceedings was accomplished by stenographic and tape recordings of the workshop. Unfortunately, both failed during the late part of the day, and the very excellent summary by Dr. John H. Taylor of the University of California, San Diego, was not recorded by either means. We regret that this occurred, and consider the loss of his insight to be significant.

The general reaction to the workshop has been very favorable. The great effort on the part of all of the participants made the session particularly meaningful. We hope that this volume of proceedings will prove useful to the planners of research programs and to those who will prepare proposals for their consideration, and that continued exchange of ideas and information will be stimulated.

Gloria Twine Chisum

FIXED WING OPERATIONS

CDR J. J. Schultz

NAVAL WEAPONS EVALUATION FACILITY

INTRODUCTION

This briefing will give an overview of the Strike (ordnance delivering) aircraft currently in the Navy/Marine Corps inventory, a brief description of their operating environment, and the aircrew's associated visual requirements. The Support aircraft (tankers, electronic warfare, photo reconnaissance, airborne early warning, etc.) will not be addressed.

A-4. The A-4 Skyhawk is a single seat, light attack aircraft, primarily employed by the Marine Corps from land bases, but is carrier capable.

A-7. The A-7 Corsair is a Navy single seat, carrier or land based, light attack aircraft.

A-6. The A-6 Intruder is a Navy and Marine Corps carrier or land based, all weather, medium attack aircraft. It has side-by-side seating for a pilot and a bombardier/navigator.

F-4. The F-4 Phantom is a Navy and Marine Corps carrier or land based fighter aircraft. It has tandem seating for a pilot and a radar intercept officer.

F-14. The F-14 Tomcat is a Navy carrier or land based fighter aircraft. It has tandem seating for a pilot and a radar intercept officer.

S-3. The S-3 Viking is a Navy carrier or land based anti-submarine warfare aircraft. The cockpit has side-by-side seating for a pilot and a co-pilot.

P-3. The P-3 Orion is a Navy land based anti-submarine warfare and maritime patrol aircraft. The cockpit has side-by-side seating for a pilot and a co-pilot.

F/A-18. The F/A-18 Hornet is a dual-mission, fighter and light attack, single seat, carrier or land based aircraft which will be employed by the Navy and Marine Corps. It is undergoing pre-production testing at the present time. Fleet introduction is scheduled for the early 1980's. It will eventually replace the A-7 and F-4.

OPERATING ENVIRONMENT

ATTACK

- SEA OR LAND TARGETS
- VERY LOW TO MEDIUM ALTITUDE FLIGHT
- 1 TO 20 AIRCRAFT FORMATIONS
- SUBSONIC SPEEDS
- SINGLE TARGET

FIGHTER

- OVER SEA OR LAND TARGETS
- VERY LOW TO HIGH ALTITUDE TARGETS
- MEDIUM TO HIGH ALTITUDE FLIGHT
- SLOW TO SUPERSONIC SPEEDS
- MULTIPLE TARGETS
- 2 AIRCRAFT FORMATIONS

ASW

- SEA TARGETS (SURFACE AND SUBSURFACE)
- VERY LOW TO MEDIUM ALTITUDE FLIGHT
- SINGLE AIRCRAFT OPERATIONS
- SUBSONIC SPEEDS
- SINGLE TARGET

INSIDE COCKPIT VISUAL REQUIREMENTS

MONITORING ENGINE AND AIRCRAFT SYSTEM PERFORMANCE

OPERATING AND MONITORING NAVIGATION EQUIPMENT AND INSTRUMENTS (IN BOTH VISUAL AND INSTRUMENT METEROLOGICAL CONDITIONS)

OPERATING TARGET DETECTION SYSTEMS (RADAR, FLIR, ETC.)

WEAPON SYSTEM OPERATION

MONITORING THREAT DISPLAY SYSTEMS

OPERATING COMMUNICATIONS EQUIPMENT

OUTSIDE COCKPIT VISUAL REQUIREMENTS

LANDING (CARRIER AND ASHORE)

TARGET ACQUISITION/IDENTIFICATION (SURFACE OR AIR)

COLLISION AVOIDANCE

TERRAIN AVOIDANCE

WEAPONS DELIVERY

THREAT DETECTION (AIRCRAFT, SAMs, AAA)

VISUAL NAVIGATION

FORMATION FLYING

OTHER CONSIDERATIONS

NIGHT FLYING

SUN EFFECTS

FORMATION FLYING
THREAT DETECTION
TARGET ACQUISITION

NUCLEAR EFFECTS

HEAT
LIGHT (FLASH BLINDNESS)
PROTECTIVE DEVICES (CLOSURES, GOGGLES, GOLD VISORS, EYEPATCH, CLOTHING)

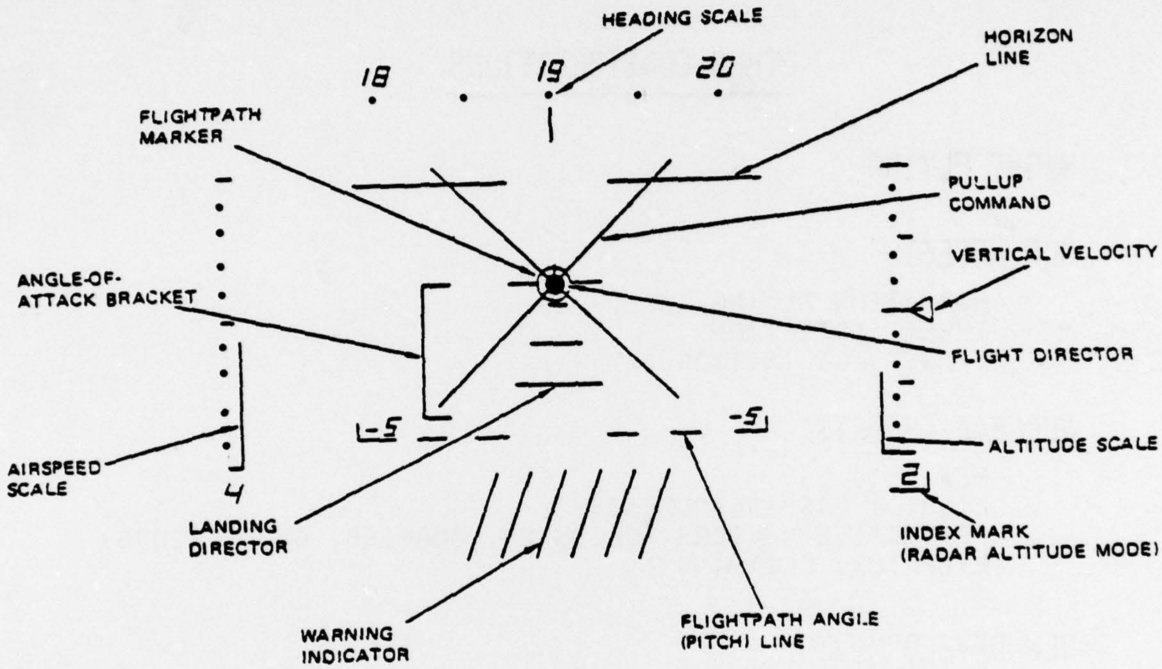
NEW DEVELOPMENTS

HEADS UP DISPLAY (HUD)
HELMET MOUNTED SIGHTS
HELMET MOUNTED SENSORS
STICK AND THROTTLE MOUNTED CONTROLS

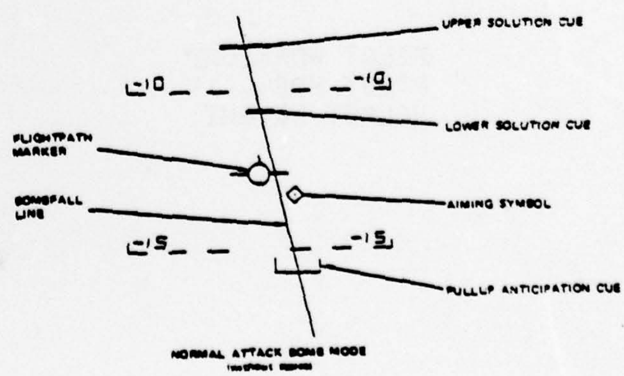
LIMITATIONS

PILOT WORKLOAD
PILOT MOBILITY
HELMET WEIGHT

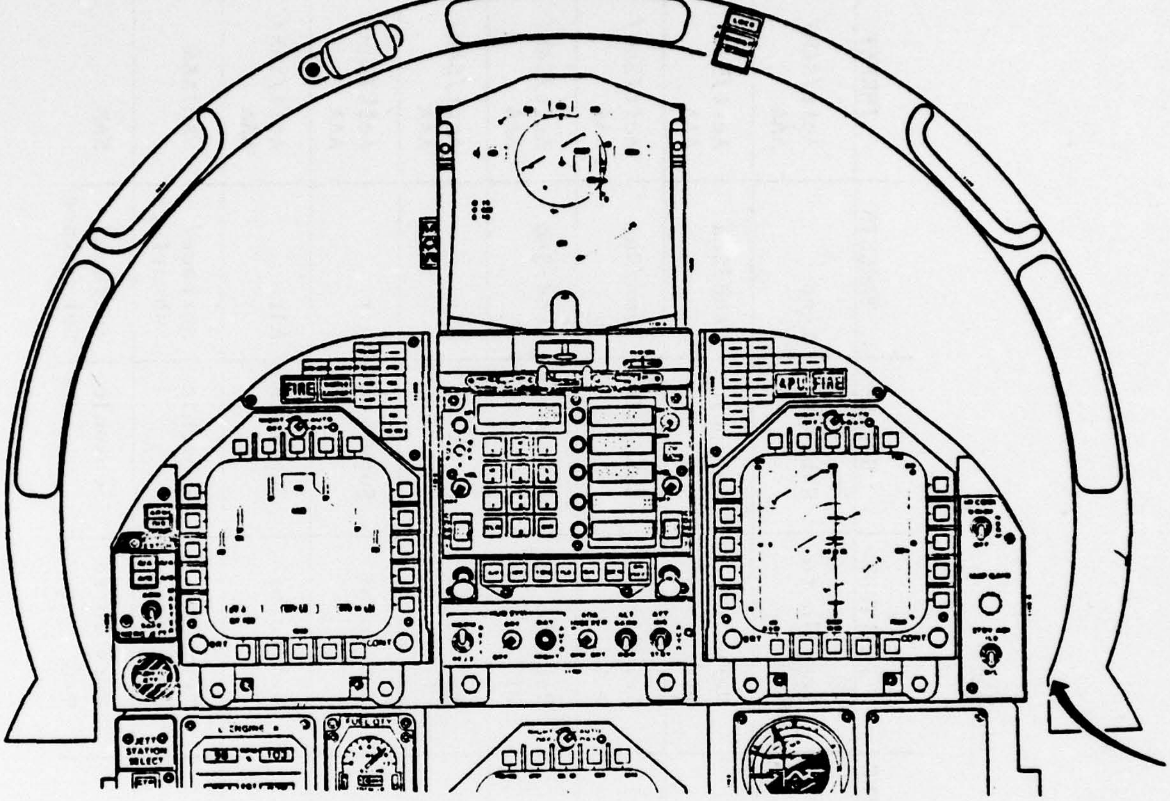
A-7E HUD SYMBOLOGY



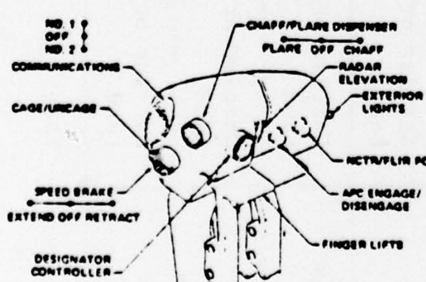
HUD ATTACK MODE SYMBOLOGY



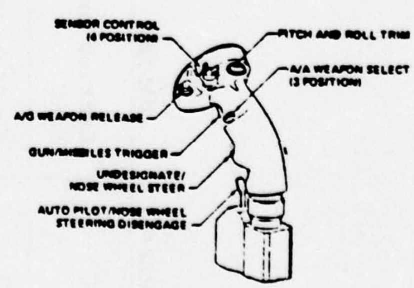
F/A-18 HUD



THROTTLES



STICK GRIP



SUMMARY

AIRCRAFT	BASING	COCKPIT SEATING	ALTITUDE	SPEED	TARGETS	THREAT	HUD
A-4	Carrier or Land	Single	Very lo to med	Subsonic	Land	Acft/SAM/ AAA	Yes
A-7	Carrier or Land	Single	Very lo to med	Subsonic	Land/Sea	Acft/SAM/ AAA	Yes
A-6	Carrier or Land	Side-by-side	Very lo to med	Subsonic	Land/Sea	Acft/SAM/ AAA	No
A-18	Carrier or Land	Single	Very lo to hi	Transonic	Land/Sea	Acft/SAM/ AAA	Yes
F-4	Carrier or Land	Tandum	Med to hi	Supersonic	Air	Acft/SAM/ AAA	No
F-14	Carrier or Land	Tandum	Med to hi	Supersonic	Air	Acft/SAM/ AAA	Yes
F-18	Carrier or Land	Single	Med to hi	Supersonic	Air	Acft/SAM/ AAA	Yes
S-3	Carrier or Land	Side-by-side	Very lo to med	Subsonic	Surface/ Subsurface	SAM/AAA	No
P-3	Land	Side-by-side	Very lo to med	Subsonic	Surface/ Subsurface	SAM	No

EDITED TRANSCRIPT

FIXED WING OPERATIONS

PRESENTATION BY COMMANDER JOHN SCHULTZ

Good morning, ladies and gentlemen. Commander John Schultz, Naval Weapons Evaluation Facility.

The first slide has nothing to do with my presentation, but that's my boss and they are paying for the trip, so I will give them the publicity.

My briefing will give you an overview of the strike, meaning the ordnance-carrying aircraft currently in the Navy-Marine Corps inventory with a brief description of their operating environment, air crews associated visual requirements. The support aircraft, tankers, electronic warfare, photo reconnaissance etc., will not be addressed.

First, a quick look at the aircraft I am talking about. This is the A-4 SKYHAWK which is a single seat, light attack aircraft, primarily employed by the Marine Corps from land bases, but it is carrier-capable.

This is the A-7 CORSAIR II. It is a Navy single seat carrier or land-based light attack aircraft.

This is the A-6 INTRUDER. It is a Navy and Marine Corps carrier or land-based all weather medium attack aircraft. It has side-by-side seating for a pilot and a bombardier-navigator.

In the fighter aircraft, we have the F-4 PHANTOM, which is again a Navy and Marine Corps carrier or land-based aircraft. It has tandom seating with the pilot in the front and the radar intercept operator in the back.

The F-14, the Navy's newest fighter. It is a Navy carrier or land-based fighter aircraft. It also has tandem seating with the pilot in the front and the radar intercept operator in the back.

In the antisubmarine warfare area, we have the S-3 VIKING. This is a carrier or land-based antisubmarine warfare aircraft. This cockpit has side-by-side seating with a pilot and a co-pilot.

The P-3 ORION is a Navy land-based antisubmarine warfare and maritime patrol aircraft. This cockpit also has side-by-side seating with a pilot and a co-pilot.

The upcoming addition to the Navy-Marine Corps inventory, is the F/A-18 HORNET. This aircraft is going to be a dual mission fighter and attack aircraft, single seat, and it will be carrier or land-based, which will be employed by the Navy and the Marine Corps. It is currently undergoing pre-production flight testing, and we expect fleet introduction in the early to mid-1980's. It will eventually replace the A-7 for the Navy in the attack role, and the F-4 for the Navy and the Marine Corps in the fighter role, and probably eventually the A-4 in the Marine role as a light attack aircraft.

A few quick words on the operating environment of these various groups of aircraft. The attack aircraft are employed against land or sea targets.

The operating environment of an attack aircraft goes from very low altitude to medium altitude, normally operating anywhere from a single aircraft up to 20 or more aircraft in a formation, depending on the target type of strike they are going on. They operate at sub-sonic speeds, and when they are employed, they generally attack a single target at a time.

Fighter aircraft will operate against air targets, obviously, over land or sea. They will normally be operating against very low to high altitude targets all the way from the wave-top skimming cruise missiles all the way up to the high altitude incoming missiles and anywhere in between for fighter attack aircraft coming in.

Their normal operating regime would be medium to high altitude area, and their speed can go anywhere from slow in a dogfight situation all the way to supersonic on an intercept.

Fighter aircraft do have a requirement to be able to engage multiple targets at one time and, of course, that is a function of the weapon systems which they have on board. Generally speaking, fighter aircraft can expect to be operating in sections of two aircraft offering mutual support to each other.

In the ASW, *antisubmarine warfare,* aircraft, they are operating against sea targets only, but it could be surface or sub-surface targets. Their operating regime is very low, at a medium altitude. They are almost always single aircraft operations, operating independently but as part of an overall large coordinated search effort. They operate at subsonic speeds, and they also will be looking at attacking a single target at a time.

Could I have the first viewgraph?

I would like to look at some of the aircrew requirements.

First, looking at what the requirements are for the aircrew, visual aids, within a cockpit. These basically apply to any type of aircraft.

The aircrew will be monitoring their aircraft engine system's performance, making sure that everything is operating properly. The same thing with the navigation and instruments. I will make a distinction here between visual and instrument meteorological conditions. Obviously, if you are flying in the visual condition, the head is out of the cockpit much more. Under instrument conditions you are not looking to the outside, so the head would be inside the cockpit continually.

The aircrew will be operating the target detection systems. They are out searching for a target and they are going to employ their systems to find it, and the majority of these systems require the head in the cockpit.

They have to be able to set up their weapons systems to attack the targets they find, and that generally requires getting into the cockpit to set up the proper switches.

They will be monitoring threat displays to let them know if the enemy has detected them, possibly illuminating them with radar in preparation to launch a missile or gunfire against them.

And, of course, operating the radio requires getting back in the cockpit and changing frequencies.

A look at outside the cockpit. One of the primary requirements is to be able to land the aircraft. I note carrier and shore; carrier being a little more of a rigid regime, requiring good outside visibility. You have got to be able to see that deck, see the meatball, and get the thing aboard.

Target acquisition and identification. Even though you do have sensors within the aircraft to maybe initially locate a target, the majority of them require visual identification by the pilot before he will launch his weapons against a target.

Collision avoidance. Obviously, you don't want to fly into another aircraft up there.

Terrain avoidance. Generally applies here to the attack aircraft. A lot of their missions involve low altitude, very low, 100, 200 foot over-land navigation routes en route to the targets, and obviously they have got to have good visibility outside to keep from flying into the hills.

Weapons delivery. Again, although the majority of the more sophisticated weapons now can be launched completely from within the cockpit on display systems, still, the bulk of the attack mission is with the old iron bombs, air-to-ground visual bombing.

Threat detection. I mentioned before, you are in the cockpit with your sensors finding if you have been detected. The sensors will give you an indication that there is a threat. Now you want to visually pick it up, whether it is an aircraft that's coming at you, a surface-to-air missile or anti-aircraft fire so you can take positive action to evade it. You have got to see it first to make your best evasive move.

Visual navigations. Again applying more to the attack role in the overland navigation low level phase. They have to see out to correlate what they are actually flying over with what their sensors or navigation systems tell them they are flying over.

Formation flying. Applies mainly to attack and fighter aircraft. Obvously, flying formation, you have to have good visual contact with the aircraft you are flying formation on. Quickly, some other considerations in vision you have to think about.

Night flying. Of course, everything that goes on inside the cockpit in the daytime applies equally at night. There are very few visual requirements that don't apply at night, with the exception perhaps of visual navigation, visual target identification. So, night flying imposes additional constraints on the pilot, and visibility is that much poorer outside the cockpit. Formation flying, for example, becomes pretty tough, but it is routinely accomplished at night.

Some of the effects are probably pretty obvious. Flying formation, if you have your leader between you and the sun, you can get yourself blinded in there and set yourself up for a possible collision with your other aircraft.

Threat detection. If you remember from the old World War II movies, zeroes rolling in out of the sun, obviously that's still a valid tactic. It's tough to see them. As I mentioned, if you

can't visually acquire the threat that's coming at you, you have a hard time countering it. The same thing for target acquisition. If you have the wrong sun angle, I am thinking here in particular the attack role, in the dusk and dawn situation, low sun angle, your position in relation to the sun and the target can make all the difference as to whether you are actually going to be able to find that target and deliver your ordnance on it.

Nuclear effects. Everything I have talked about so far on visual requirements dictates that you want a big canopy, unobstructed, lots of good outside visibility. Now here that's going to be working against you. When you look to nuclear effects, there are two primary areas as far as the cockpit is concerned: The heat and the light, your flash blindness. The more cockpit area you have got, the more vulnerable the pilot is. We do have some protective devices that are currently available. Thermal closures, a clam shell, which the pilot can pull down and completely enclose the canopy, which will block out the light flash and also the heat. These are problems, because once that clam shell is down, obviously the aircrew has no outside visual contact. They are strictly on their instruments. They have goggles that will sense when a brilliant flash of light from a nuclear detonation goes and almost instantaneously go opaque to protect the aircrew from flash blindness. They have gold visors, gold-tinted visors you can put in your helmet which cuts a lot of the ambient light coming in, and it will reduce the severity of the flash blindness. Then the eye patch, the standard eye patch over one eye. You can fly with it so when the first flash goes off, you are only blinded in one eye. You take your eye patch off, and when the next flash goes, then you are out of business. Airmen's clothing, that's mainly for thermal protection. The white flight suits, the white helmet, the white clothing to reduce heat absorption from a nuclear blast.

Some of the new developments - I say "new", a lot of them are in the fleet now, but they are being constantly improved. They have been in recent years great aids to the pilot as far as visual requirements. Head-up Displays (HUDs) are unit mounted, directly in front of the pilot, allowing him to to keep his head out of the cockpit and still monitor what is going on inside the aircraft. I have a viewgraph that will show that in a minute. **Helmet mounted sights** - there are systems where the gun sight can be projected on the visor of the helmet so that the pilot is not restricted to looking straight ahead through a fixed gun sight but can move his head from side to side and find his targets and designate them without being restricted strictly to the forward sector of the aircraft. **Helmet mounted sensors** - the one that comes to mind here is the laser detection sensor mounted on the helmet. If the aircraft is being illuminated by a laser or is receiving reflected laser energy from a target that he is looking for to deliver a laser-guided bomb on, he doesn't have to go into the cockpit to find where this is coming from. You have little dots and displays on the visor. He just moves his head and lines it up and he finds his target that way. One big one that is coming along more and more now is the stick and throttle mounted controls. This is again an attempt to keep the pilot from having to move his head in the cockpit to find a switch to work. Mount them all on the throttles or on the stick so he knows by feel which switches he has, and he can keep his head out of the cockpit. Right now they are generally the attack weapons systems selection and some of the navigation functions. He can keep his eye on the target and go ahead and select his weapons or modify them, whatever he going to do, without having to stick his head back in the cockpit.

Some limitations; we have to keep in mind pilot workload. Essentially, the more information displayed for him on a HUD or a helmet mounted sight or whatever it is, it is going to be tougher for him to pick out that vital piece of information he needs at that one particular time.

Pilot mobility. It is a requirement, particularly in the fighter aircraft and attack aircraft, to be able to move freely in that cockpit; get your head almost 180 degrees behind you to see if anyone is on your tail coming in, and the more you mount on the pilot's helmet, you tend to restrict him a little bit in his movements. Of course, helmet weight, anything you hand up there, when you are pulling four or five, even six G's, that added weight on the helmet is greatly multiplied, adding pilot fatigue and workload there in the cockpit.

A quick look at one of the current HUDs, the A-7E aircraft. At the bottom is a picture of what it looks like and a couple of different displays which show some of the types of information that can be dipplayed there. I might point out that copies af all of these figures will be available in the minutes so you can go into the details then.

The F/A-18 is our newest aircraft coming out. This figure gives a more overall picture of the aircraft with the HUD mounted up there, and it has similar information as that for the A-7E, although the F-18 can display more information than the A-7 can. Look there at the bottom under the throttle and stick grip. You will see various controls that are being added in this aircraft to give the pilot the capability to change his weapons selection, sensors, without going into the cockpit and physically finding a box and turning a switch.

The final slide is just a summary put together showing the various types of aircraft and some of the high points of them. Again, it will be in the notes when you receive them. It gives you a kind of a composite to refer to for comparisons.

mw

CDR. J. J. SCHULTZ

DISCUSSION

DR. COHEN: You mentioned the vital dynamic effects of the G forces acting on the helmet that heads up the display, but throughout your discussion I didn't see much comment as far as the effects of G forces on blackout and consciousness from an operational point of view. Now, as the aircraft gets higher and higher in performance characteristics, the G loading capability of the air frames are far exceeding the capabilities of the operators. Yet from an operational point of view, I have seen very little commentary as to this limitation. Do the operators in fact feel that they are limited by these G loading?

CDR. SCHULTZ: I can only personally speak from the attack arena because that is my background. Other than when we get into the air-to-air combat maneuvering, practicing defensive tactics, the G loading in the attack mission generally comes after you have delivered your weapons and are pulling out. So, your major mission is done. You have this weapon off and now you are coming out or getting off target. It's of low duration. You are talking about five to seven seconds on a G pullout or a loft-weapon delivery of 10, 15 seconds. With the attack aircraft, I don't see it as a problem.

MAJOR LILLIE: With more power added to the coming attack and fighter aircraft, they have the ability to sustain high G load for a much longer time period. Therefore, you end up with a situation in which you get to a point where you are going to black out or you can only pull to a point and maintain say, six G's. Each pilot's tolerance is very different; you can build that tolerance up. But each individual is going to have a specific point- -some people can handle 8 G's, but most airplanes are now stressed for only what they are designed for.

DR. COHEN: But the F-18 and the F-14 should have considerably higher G characteristics. The problem that I see emerging is a deficit in terms of the capability of the man to take advantage of the capability for the air frame, particularly for air combat maneuvering and missile evasion and so on. At the same time, I see the operational people not really being concerned about this to the degree that the medical community is concerned about it. I would like to get some feel from somebody who is in weapons evaluation as to how they perceive the problem or if the problem is merely a creation of the medical community.

CRD. SCHULTZ: I don't know if we are really talking about too much of an increase in G loading. On the newer aircraft, the F-18, we are talking about seven and a half G's.

MAJOR LILLIE: That's right.

CDR. SCHULTZ: The operational envelope, I think, we are maintaining fairly constant the last few years. Obviously, it's a problem.

MAJOR LILLIE: I think he's exactly right. The aircraft is designed with stress limits. You have got to meet a seven and a half G criterion without breaking the airplane, and you have to be able to maintain seven and a half G's.

If you have a stronger powerplant, it gives you the ability to maintain seven G's for a period of time maybe greater. Each new airplane can maintain it for two minutes. Maybe an-

other airplane can maintain it for five minutes steadily. It's normally not that long. Sometimes you can only maintain it for 30 seconds.

DR. COHEN: I was under the impression that the F-14 and F-18 could sustain higher G loadings than the F-4 for prolonged periods on the order of greater than seven- -

MAJOR LILLIE: Yes, you probably could.

DR. COHEN: I just wondered if the operational people have taken this into account and recognized it is an operational problem in air combat maneuvering.

CDR SCHULTZ: I don't recall it ever being addressed in the attack community. It's something that you live with. Like I say, it's for a fairly brief period in the attack mission. So we don't get too concerned about it.

DR. JOHN O'HARE: Your discussion has focused on the pilot principally. Do you have anything to say about the visual requirements of the people in the back seat, the crew?

CDR. SCHULTZ: The majority of them are strictly sensor operators. They are not looking outside, if that's the type of thing you are talking about.

DR. O'HARE: Well, certainly they have visual requirements to see sensors and other equipment.

CDR SCHULTZ: All inside the aircraft have requirements to be able to operate the equipment that is assigned to them.

DR. O'HARE: I am thinking mostly of the interaction and transfer of information between the pilot and that crew member in some mission, particularly as to its visual components.

CDR SCHULTZ: Again, I can't speak too much for the fighter end, but I know the backseater in a fighter can really augment the pilot in a lot of cases. I have heard of the backseater fighting the fight, telling the pilot which way to turn and when to pull, and the pilot never sees the aircraft; he might get a kill on it because the guy in the back seat is doing it for him.

But people inside the aircraft- -like the S-3, in the back they have a little window where the guy can look out the side just so they know they are still in the air, I guess. But they are looking at the radar scope or something like that all the time. Their coordination, visual, is strictly passing sensor information up to the pilot. The majority can automatically be displayed to the pilot without any verbal interaction back and forth with him.

DR. CHISUM: Which kinds of displays are they looking at in the back seat? Do they have cathode ray tubes?

CDR SCHULTZ: They have moving pen and paper graphic readouts.

DR. LIT (Southern Illinois University): I presume this has been human factored in its original development, has it not, and possible sources of difficulty pointed out? Is there a follow-up on these issues as it becomes operational and is there feedback to somebody?

CDR SCHULTZ: Any new aircraft or system that goes into an aircraft goes through technical evaluation, operational evaluation. Human factors are one of the major areas that are looked at. Once the system is bought, generally if problems develop, they will develop in the fleet. They will start getting reports in from their operators that there is a problem with a particular piece of gear, e.g., the location of control doesn't lend itself to a proper operation of the equipment. If there is enough feedback coming in that indicates it is a general problem, then they investigate it and there may be a modification made to that particular piece of equipment. But human factors is definitely looked at as a separate part of each new weapons system as it is developed.

DR. LIT: Have you been aware of any special visual problems or human operators problems that those who are not part of the military can think about in terms of applying scientific knowledge to this issue?

CDR SCHULTZ: Well, one thing that comes to mind is the F-18 aircraft. We have been looking at it at NWEF from a nuclear system point of view, and our primary nuclear control box is stuffed on the console on the right-hand side. It's very difficult for a pilot to make the proper selection while flying at 100 feet over the ground trying to visually navigate into his target.

DR. REINECKE: I wonder if you could give us any indication of the visual field requirements versus what you have for these jobs and the visual acuity design of the instruments. For example, are the gauges and all these sorts of things printed in 20/200 or 20/20 figures? Since we are talking about visual requirements, I wonder what they are. I haven't seen any specifications as to the visual field, what you would like versus what you have; or your acuity, what you have versus what you would like.

COL TREDICI: This isn't quite done as simplistically as Dr. Lit or as the Commander mentioned. The instruments are not fed back the other way and decided, first, should they be 20/70 visible. They are made to fit the cockpit to the best size that they have up to now. Then the visual requirements really come back the other way, which is to pick the best people you have. And they are able to do that. That's why some of these other problems have come up. There hasn't been a coordination. For instance, the navigators have usually come from a group who are deficient visually. Then they stuck them back in the back seat when they weren't navigators per se anymore or "scope-looker-aters". So, they are now looking for airplanes just as well as the pilot. We have to have a reconsideration of that whole standard.

CDR SCHULTZ: My pet problem and peeve with inside the cockpit instrumentation is parallax. You can get yourself in some bad trouble with a gauge setting all the way over, particularly a clock, and you'll read it two minutes off. It's very distracting and sometimes can be very costly.

HELICOPTER/SEARCH AND RESCUE

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Of all the missions of the Coast Guard, Search and Rescue (SAR) remains the most visible with the general public and the one with which we are usually identified. The Coast Guard annually prosecutes over 75,000 SAR cases using a variety of ships and aircraft, and the vast majority of these require visual location/identification of the distressed unit. From a total of 30 Air Stations the Coast Guard operates approximately 100 helicopters and 50 fixed wing aircraft, and these are involved in over 7,000 SAR cases annually. The Coast Guard's motto of Semper Paratus, or Always Ready, requires that we be ready to provide assistance regardless of the environmental conditions or time of day or night.

Present Coast Guard R&D Projects to improve capabilities in the SAR mission area may be divided into three general areas:

1. Develop better electronic sensors for use in detection and identification of distressed units, in particular during periods of reduced visibility.

2. Develop better search platforms and rescue equipment.

3. Improve effectiveness of Coast Guard search in the maritime region through the development of reliable search planning techniques, improvement of the methodology of conducting a search, and accurate evaluation of the search results.

The third of these is of most interest to this Workshop. Present searches are conducted using World War II visual search techniques which have been updated only once from sighting data collected 23 years ago. The concept of sweep width, which is the performance measure utilized by SAR mission coordinators to plan searches, is depicted in Figure 1. The last update of the sweep width tables (in 1968) did not include the effects of such essential variables as search vehicle speed and search duration.

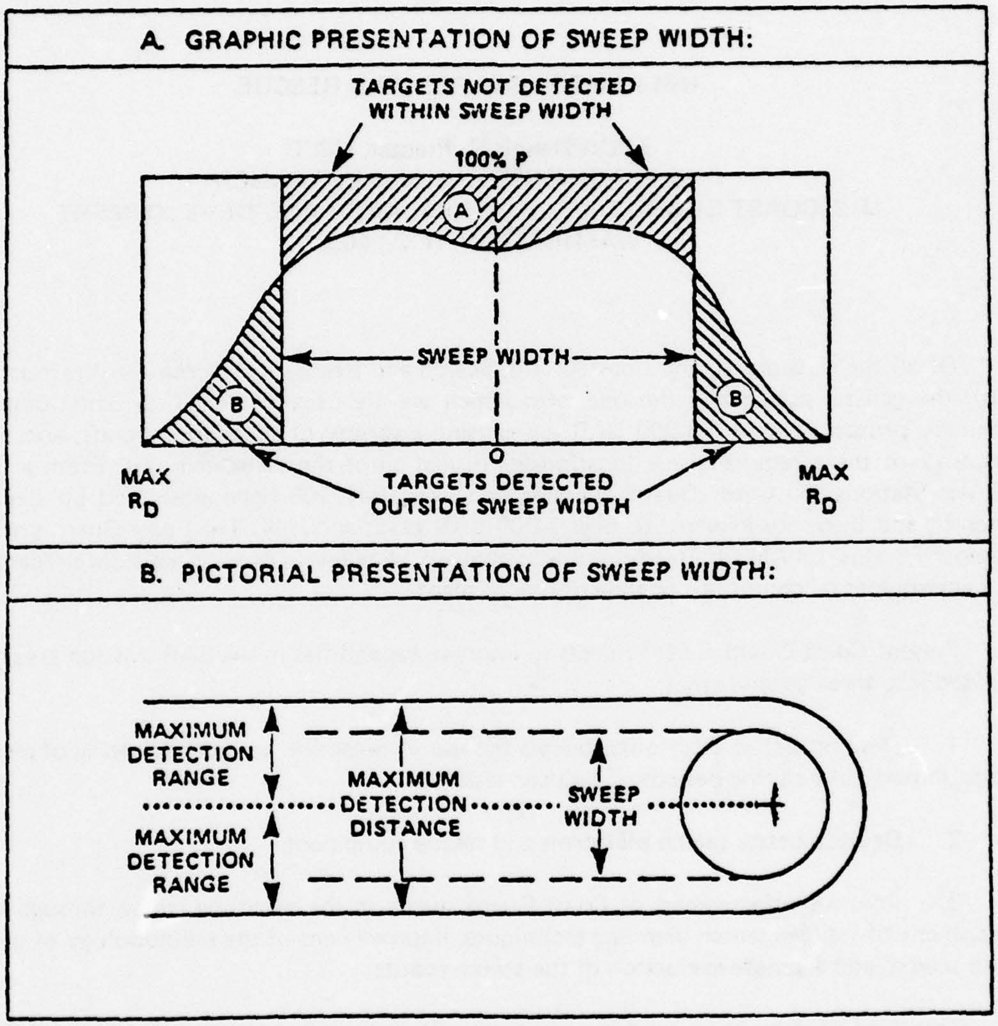

FIGURE 1. GRAPHIC AND PICTORIAL PRESENTATION OF SWEEP WIDTH

The objectives of the Improved Probability of Detection in SAR project are to:

1. Develop a more precise visual sweep width model

2. Develop electronic sweep width models

3. Formulate Probability of Detection to fit actual search

4. Improve target drift predictions

To this end, initial testing in September/October 1978 and upcoming from 16 April through 25 May 1979 is concerned with determining those environmental, search unit, and target characteristics which influence the search performance of boats, cutters, helicopters, and fixed wing aircraft in detecting persons in the water, life rafts, and various sizes of boats. Of the 24 parameters (Figure 2) having a potential influence on sweep width, only five are presently used and their significance is uncertain. Figure 3 depicts the present sweep width tables. Figure 4 shows the Exercise Area in which the tests are being conducted; the remainder of my presentation concerns interim results obtained from the Fall 1978 experiment. Excerpts from the Interim Report are attached; the full document is available through the National Technical Information Service.

PRIMARY VARIABLES

1. Search Unit Type
2. Target Type and Size *
3. Visibility *
4. Altitude *
5. Search Speed
6. Search Duration
7. Target and Background Contrast
8. Wing Speed *
9. Sun's Elevation
10. Swell Height
11. Cloud Cover *

INTERDEPENDENT HUMAN FACTORS

1. Fatigue
2. Stress (noise, glare, vibration, temperature, motion, etc.)
3. Visual Acuity and Perception
4. Training Level
5. Experience Level
6. Motivation Level
7. Position of Lookouts

SECONDARY PARAMETERS

1. Number of Lookouts
2. Target Movement and Aspect
3. Relative Wind Direction
4. Sun's Relative Bearing
5. Lookout Briefings
6. Visual Aids

* Presently Utilized

FIGURE 2.

APPENDIX C

NATIONAL SAR MANUAL SWEEP WIDTH TABLES

Sweep Width (W) For Visual Search
(W Given In Nautical Miles)

[illegible]	Liferafts 0	Liferafts 5	Liferafts 10	Liferafts 20	Boats (less than 30') 0	Boats (less than 30') 5	Boats (less than 30') 10	Boats (less than 30') 20	Boats (less than 30') 30	Boats (30'-60') 0	Boats (30'-60') 5	Boats (30'-60') 10	Boats (30'-60') 20	Boats (30'-60') 30
1	0.5	0.5	0.5	-	0.5	0.5	0.5	-	-	0.5	0.5	0.5	-	-
3	1.0	1.2	1.2	1.0	2.5	2.4	2.3	1.8	0.4	3.5	3.0	2.7	1.8	0.4
5	1.4	1.6	1.6	2.3	2.7	2.7	2.7	3.2	3.3	4.2	4.2	4.2	4.2	3.3
10	1.8	1.8	2.1	3.6	3.9	4.0	4.2	4.5	5.0	6.5	6.7	6.2	6.7	6.5
15	1.9	1.9	2.6	3.6	5.2	5.3	5.5	6.7	7.0	8.5	8.5	8.4	8.4	8.3
20	2.0	2.1	2.8	3.6	5.3	5.6	6.2	6.8	7.1	8.6	8.8	9.0	9.1	8.9
30	2.2	2.3	2.9	3.6	5.5	6.2	7.0	7.0	7.1	8.7	9.5	10.4	10.1	9.7
40	2.2	2.4	2.9	3.6	5.6	6.3	7.1	7.1	7.2	8.9	10.0	11.0	10.8	10.3
50	2.2	2.4	3.0	3.6	5.7	6.4	7.2	7.2	7.3	9.0	10.0	11.9	11.3	10.7

[illegible]	Boats (60'-90') 0	Boats (60'-90') 5	Boats (60'-90') 10	Boats (60'-90') 20	Boats (60'-90') 30	Small Ships (100-1000 Gross Tons) 0	Small Ships 5	Small Ships 10	Small Ships 20	Small Ships 30
1	1.3	0.5	0.5	-	-	1.0	1.0	1.0	-	-
3	3.9	3.0	3.2	1.8	0.4	4.7	3.8	3.2	1.8	0.4
5	5.0	5.0	4.9	4.7	3.3	7.1	6.7	6.2	4.9	3.3
10	8.0	8.0	7.9	7.7	7.2	11.0	10.0	9.8	8.6	7.2
15	11.0	9.9	9.6	9.1	8.5	13.0	12.7	12.0	10.5	9.1
20	12.0	11.0	10.6	10.0	9.3	15.0	14.3	13.5	11.9	10.4
30	12.5	12.5	12.1	11.3	10.5	17.0	16.5	15.7	13.9	12.2
40	13.0	11.0	13.2	12.2	11.3	17.0	17.0	17.2	15.3	13.5
50	13.5	11.5	14.0	13.0	11.9	20.0	19.3	18.4	16.4	14.5

[illegible]	Medium Ships (1000-10,000 Gross Tons) 0	Medium Ships 5	Medium Ships 10	Medium Ships 20	Medium Ships 30	Large Ships (Over 10,000 Gross Tons) 0	Large Ships 5	Large Ships 10	Large Ships 20	Large Ships 30
1	1.0	1.0	1.0	-	-	1.0	1.0	[illegible]	-	-
3	4.6	4.0	3.3	1.8	0.4	4.7	4.0	3.3	1.8	0.4
5	8.0	7.0	6.2	4.9	3.3	8.0	7.0	6.6	4.9	3.3
10	11.0	10.6	10.2	9.8	7.2	11.0	10.6	10.2	9.8	7.2
15	14.0	13.7	13.3	11.4	9.4	14.0	13.9	13.7	11.6	9.5
20	15.0	15.0	15.1	13.0	10.9	15.0	15.0	15.6	13.3	11.1
30	17.0	17.0	17.0	15.4	13.1	17.0	17.0	17.0	15.8	13.4
40	17.0	17.0	18.0	17.1	14.7	17.0	17.0	18.0	17.5	15.0
50	20.0	21.0	20.0	18.3	15.9	20.0	21.0	21.0	18.9	16.5

Figure [illegible]

WHITECAP CORRECTION FACTOR

Wind (kts)	0	10	15	20	25	30	40	50	60
Rafts	0.8	1.0	0.9	0.7	0.5	0.2	0.1	-	-
Boats	0.9	1.0	1.1	1.0	0.9	0.7	0.2	-	-
Ships	1.1	1.0	1.0	0.9	0.8	0.7	0.5	0.2	-
Dye Marker	0.9	1.0	1.0	0.9	0.6	0.4	0.2	-	-
Smoke	0.8	1.0	0.8	0.6	0.4	0.2	0.1	-	-

Figure [illegible]

SIGHTING CORRECTION FACTOR

Percent Cloud Cover	0	10	20	30	40	50	60	70	80	90	100
Cloud Cover Factor	1.1	1.1	1.1	1.0	1.0	1.0	1.0	0.9	0.9	0.8	0.7

Figure [illegible]

FIGURE 3.

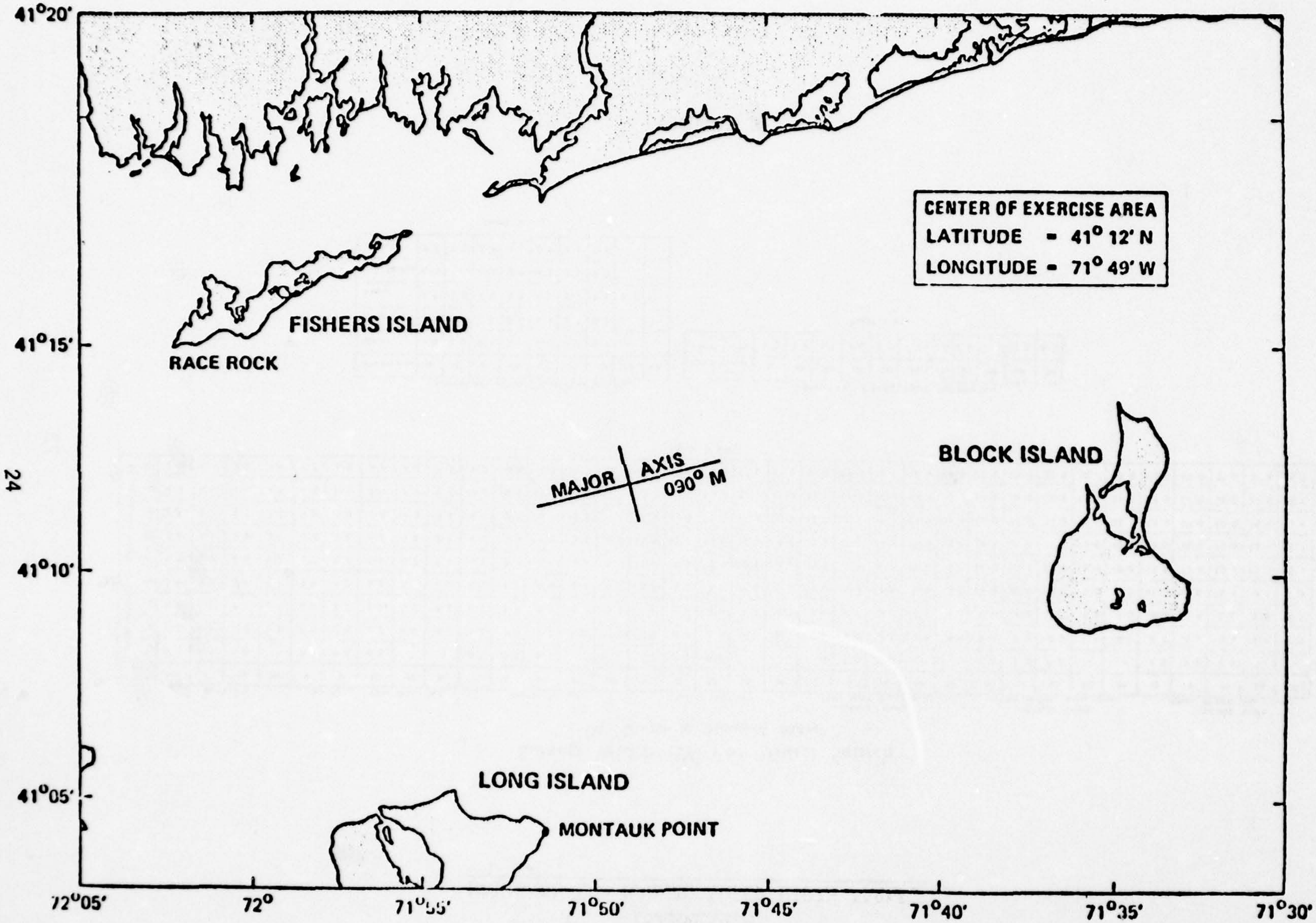

FIGURE 4. SEARCH AREA

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ANALYSIS OF VISUAL DETECTION PERFORMANCE
(FALL 1978 EXPERIMENT)

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WASHINGTON, D. C. 20590

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EXECUTIVE SUMMARY

INTRODUCTION

This report is an analysis of a Coast Guard Research and Development (R&D) Center visual detection experiment conducted from 11 September 1978 to 6 October 1978. This was the first in a series of detection experiments designed to improve search planning guidance contained in the **National Search and Rescue Manual (USCG, 1973)**. A description of the planning and conduct of this experiment is also provided, along with conclusions and recommendations for improving the quality and efficiency of future experiments.

Sweep width is the performance measure used by Search and Rescue (SAR) mission coordinators to plan SAR searches. Conceptually, sweep width defines the swath cut by a Search and Rescue Unit (SRU) inside which targets are assumed to be detected with certainty (and outside which it is assumed they remain undetected). This simplification of the concept of probability of detection provides a viable tool for planning SAR operations.

However, the need for a re-evaluation of the **National Search and Rescue Manual** (SAR Manual) sweep width tables has long been apparent, both from the standpoint of improving their accuracy, as well as determining whether additional parameters not previously considered may significantly influence sweep width. Thus, this series of experiments, will evaluate the search performance of SRUs in detecting persons in the water, life rafts, and various sizes of boats for a representative set of environmental conditions.

The types of SRUs evaluated in this initial experiment were 82/95 foot cutters, 41/44 foot boats, helicopters and fixed wing aircraft. The targets were white, 16 foot open boats set at anchor. The influence of the following parameters upon sweep width was investigated:

1. Search Speed
2. Visibility
3. Wind Speed
4. Swell Height
5. Cloud Cover
6. Elevation of Sun

7. Duration of Search

8. Search Unit Type

The controlled experiment was conducted in Block Island Sound with sufficient repetitions to ensure validity and accuracy of results. (A total of 695 detection opportunities were generated). A relatively sophisticated logistic regression computer program was used to model the lateral range curves upon which sweep width estimates were based.

RESULTS

Cutter and 41/44 foot boat sweep widths were found to be sensitive to swell height, wind speed, cloud cover, search unit type and duration of search; whereas aircraft sweep widths were sensitive to visibility, wind speed, and search unit type.

Table 1 provides an overview of sweep width values for each SRU type corresponding to environmental conditions which ranged from excellent to poor. Estimates of sweep width are not provided for aircraft in a poor environment since no aircraft searches were conducted under these conditions.

CONCLUSIONS

The scientific method used for the conduct and analysis of this controlled experiment was successful in meeting the stated objectives. For the environmental conditions experienced during this experiment, the following specific conclusions can be drawn:

1. For fixed wing aircraft, an increase in search speed was found to reduce sweep width, while for cutters, boats, and helicopters an increase in search speed was **not** found to degrade search performance. Thus cutters, boats, and helicopters should search at the maximum speed that environmental conditions will permit. This will minimize the time required to search a particular area with a given probability of detection.

2. Surface craft search performance degraded more rapidly as environmental conditions deteriorated than is predicted by the SAR Manual. (Aircraft did not search under as wide a range of environmental conditions as surface craft. Thus, while a similar conclusion could not be drawn concerning aircraft search performance, there is no assurance that such an effect does **not** exist).

3. The degradation of surface craft and helicopter performance over the course of a search was significant. For surface craft under marginal conditions (20 knots wind speed and 4 feet swells) after four hours of search, sweep width was reduced by as much as 43 percent. Helicopters exhibited a similar reduction in performance over a two hour search. This dramatic reduction in sweep width as a search progresses underscores the necessity for understanding the human factors that contribute to this reduction so that the effects can, if possible, be reduced.

4. Sweep width was found to continually decrease as wind speed increased from 1 to 25 knots. These results are in conflict with the SAR Manual sweep width tables that predict an

TABLE 1. COMPARISON OF AIRCRAFT AND SURFACE CRAFT SWEEP WIDTHS

UNIT TYPE	SWEEP WIDTH (nm)	ENVIRONMENTAL CONDITIONS: VISIBILITY (nm)	WIND SPEED (KNOTS)	CLOUD COVER (%)	SWELL HEIGHT (FEET)
		EXCELLENT CONDITIONS			
Helicopters Fixed Wing Aircraft 82'/95' Cutters 41'/44' Boats	7.5 5.9 5.5 4.8	15	1	0	1
		GOOD CONDITIONS			
82'/95' Cutters 41'/44' Boats Helicopters Fixed Wing Aircraft	3.8 3.1 3.2 1.9	10	10	0	2
		FAIR CONDITIONS			
82'/95' Cutters 41'/44' Boats Helicopters Fixed Wing Aircraft	2.7 2.1 2.2 1.2	8	12	100	2
		POOR CONDITIONS			
82'/95' Cutters 41'/44' Boats Helicopters Fixed Wing Aircraft	0.9 0.6 - -	-	20	100	4

Note: Surface craft mean search duration 2 hours. Helicopter mean search duration 45 minutes. Fixed wing aircraft mean search speed 150 knots.
Significant surface craft variables: wind speed; cloud cover; swell height; search duration; search unit type.
Significant airborne craft variables: visibility; wind speed; search unit type.

increase in sweep width as wind speed increases from 0 to 10 knots, followed by a continued **decrease** in sweep width as wind speed increases above 10 knots. The SAR Manual explains the increase in sweep width as wind speed goes from 0 to 10 knots by predicting that "with small targets on glassy seas. . .difficulty will be experienced in detection due to the reflections of sun, sky, and clouds on the sea surface." However, these particular environmental conditions seem relatively unlikely. Thus representing the influence of wind speed on sweep width as a monotonically decreasing function seems, by preliminary assessment, to be more appropriate. Subsequent experiments should serve to either substantiate or disprove this hypothesis.

5. The type of search unit was found to be a significant parameter in determining sweep width. Cutters performed better than SAR boats, and helicopters outperformed fixed wing aircraft. The sweep width tables of the SAR Manual give only one sweep width for surface vessel search and one for each of three altitudes of aircraft search under any set of environmental conditions. The sweep width tables predict increasing performance with altitude up to 2000 feet. Since there are performance differences between such unit types, a distinction should be made in the sweep width model. An evaluation of the effects of altitude on detection are warranted since the fixed wing aircraft flying at a higher altitude did not perform as well as helicopters.

6. For surface craft, under the most extreme environmental conditions experienced during the experiment (wind speed of approximately 20 knots, 4 to 5 feet swells and 100 percent cloud cover) the estimated probability of detection for targets that passed close aboard (near zero lateral range) was as low as 32 percent. For the most extreme environmental conditions experienced by aircraft (8 nautical mile meteorological visibility and wind speed of 12 knots) the probability of detection for contacts that passed close aboard was as low as 45 percent. Since the relatively low probabilities of detection may not be consistent with the probability of detection versus coverage factor curves of the SAR Manual, a comparison would be warranted to ensure that the probability of detection estimates derived from this figure are accurate over a range of environmental conditions.

7. While the amount of data collected with a 16 foot boat target provided a good deal of confidence about the validity of the results, the limited range of environmental conditions experienced restricts application of these results. In order to allow more general use of results, detection data should be collected for the following additional conditions:

1. Low meteorological visibility (5 nautical miles or less)
2. Wind speed greater than 15 knots and swell height 3 feet or greater (aircraft only)
3. First/last light searches (elevation of sun less than 30 degrees)
4. Overcast days (aircraft only).

RECOMMENDATIONS

In order to make comprehensive recommendations on changes to the **National Search and Rescue Manual** visual sweep width tables, additional experiments each of 5 to 6 weeks in

duration should be conducted with the following types of SAR targets:

1. Persons in the water (PIW)
2. Life rafts
3. 30 foot boats
4. 45 foot boats.

The experiments should be conducted over a wide range of environmental conditions so that the results have general application. A data base of 450 observations each for surface craft and aircraft should be collected for each target type to determine parameter significance and estimate the sensitivity of sweep to changes in these significant variables.

TABLE 3-3. SWEEP WIDTH VALUES (FIXED WING AIRCRAFT)

SWEEP WIDTH* (nm)	ENVIRONMENTAL CONDITIONS	
	VISIBILITY (nm)	WIND SPEED (KNOTS)
5.9 ±1.1	15	1
4.5 ±.9	15	5
3.8 ±.8	15	7
2.7 ±.7	10	7
2.3 ±.7	8	7
1.9 ±.7	10	10
1.6 ±.6	8	10
1.2 ±.6	8	12

*Value shown is best estimate with 90 percent confidence bounds (i.e., 95% confidence that the sweep width is no less than the lower bound).

TABLE 3-4. SWEEP WIDTH VALUES (ALL HELICOPTERS)

SWEEP WIDTH* (nm)	ENVIRONMENTAL CONDITIONS	
	VISIBILITY (nm)	WINDSPEED (KNOTS)
7.5 ±1.3	15	1
6.1 ±1.0	15	5
5.3 ±.9	15	7
4.9 ±1.5	25	15
4.3 ±.8	15	10
4.2 ±.8	10	7
3.7 ±.9	8	7
3.2 ±.8	10	10
2.7 ±.8	8	10
2.2 ±.8	8	12

*The value shown is best estimate and 90 percent confidence bounds (i.e., 95% confidence that the sweep width is no less than the lower bound).

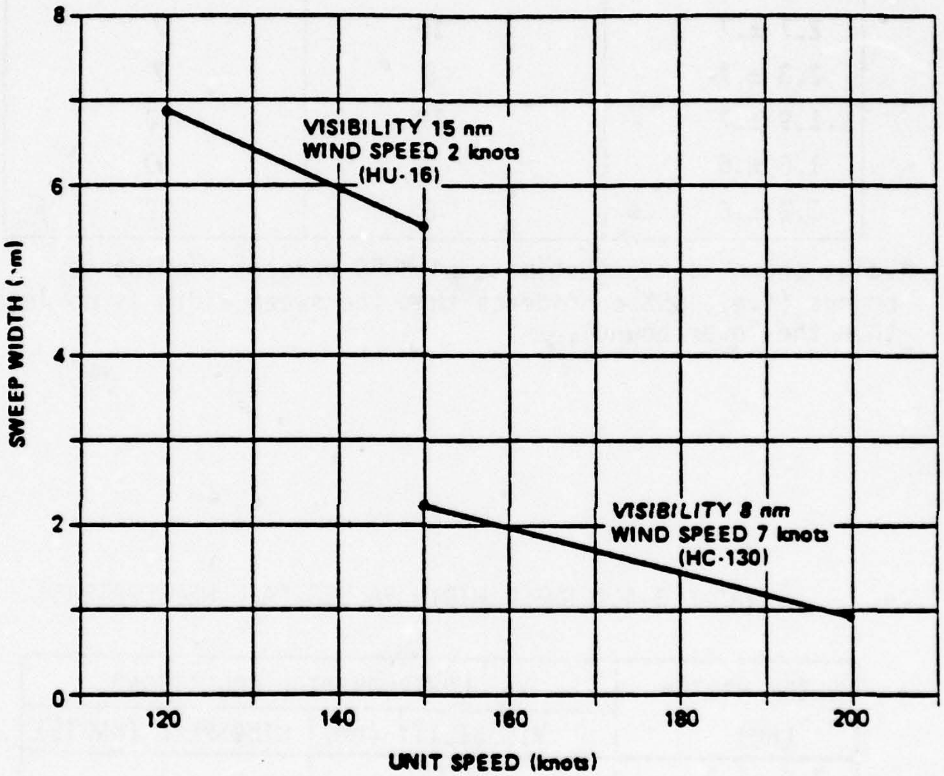

FIGURE 3-7. INFLUENCE OF SEARCH SPEED ON SWEEP WIDTH (FIXED WING AIRCRAFT)

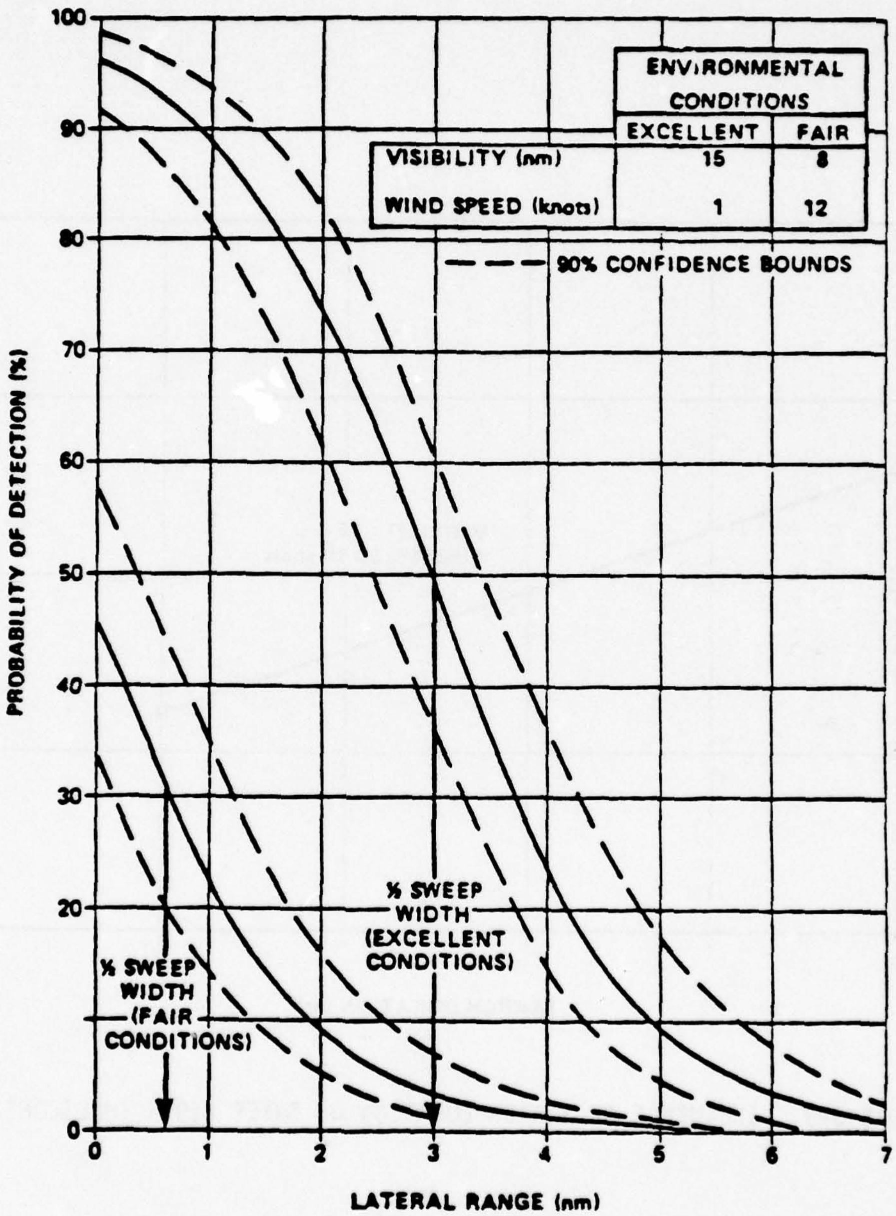

FIGURE 3-8. LATERAL RANGE CURVES FOR FIXED WING AIRCRAFT

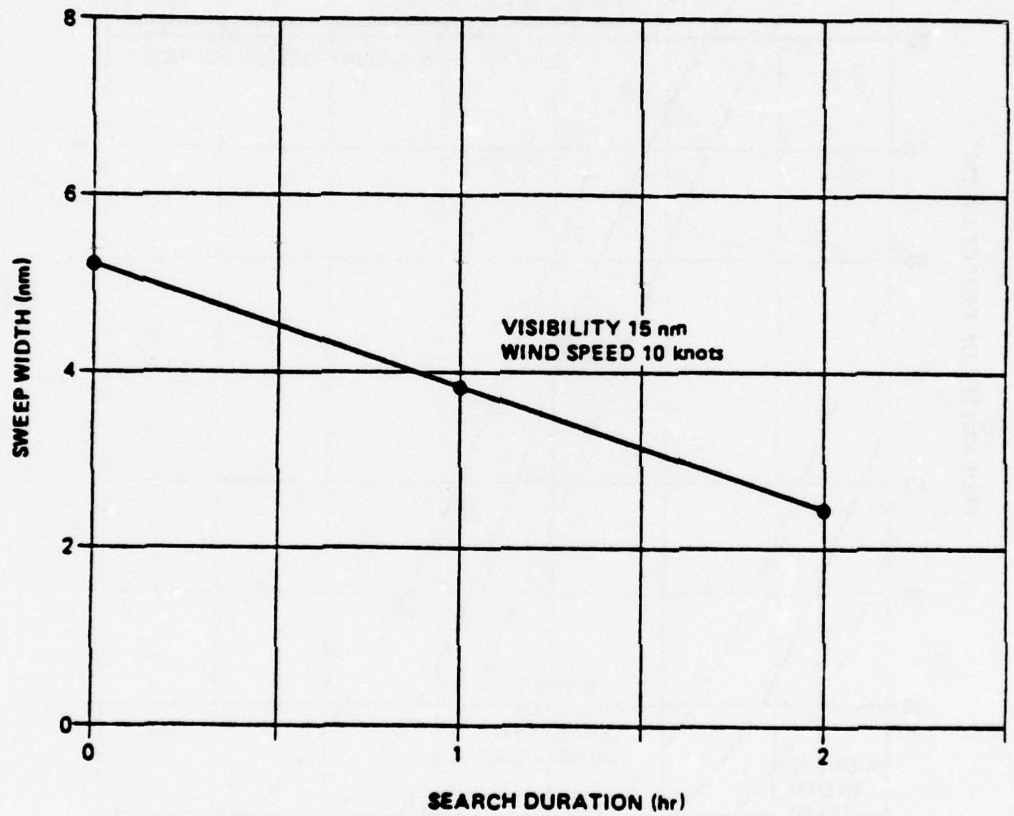

FIGURE 3-9. INFLUENCE OF SEARCH DURATION ON SWEEP WIDTH (HELICOPTER)

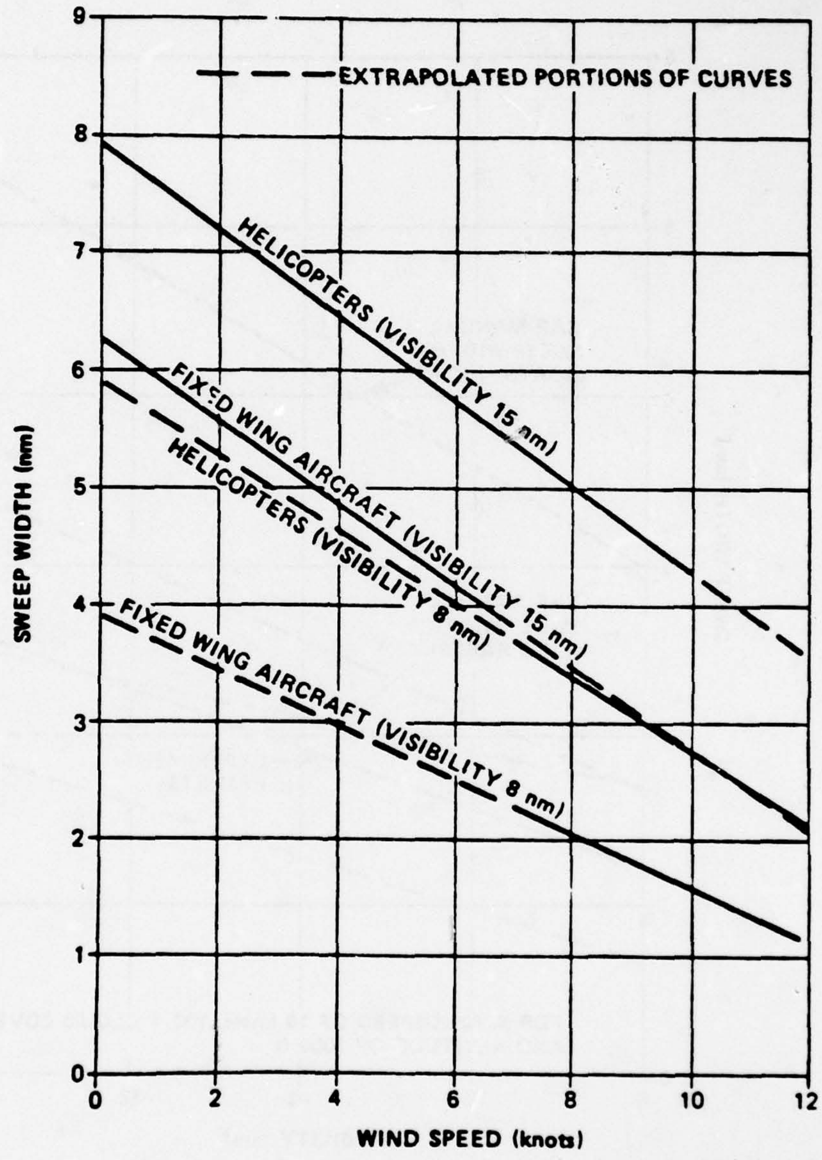

FIGURE 3-10. COMPARISON OF FIXED WING AIRCRAFT AND HELICOPTER SWEEP WIDTHS AS A FUNCTION OF WIND SPEED AND VISIBILITY

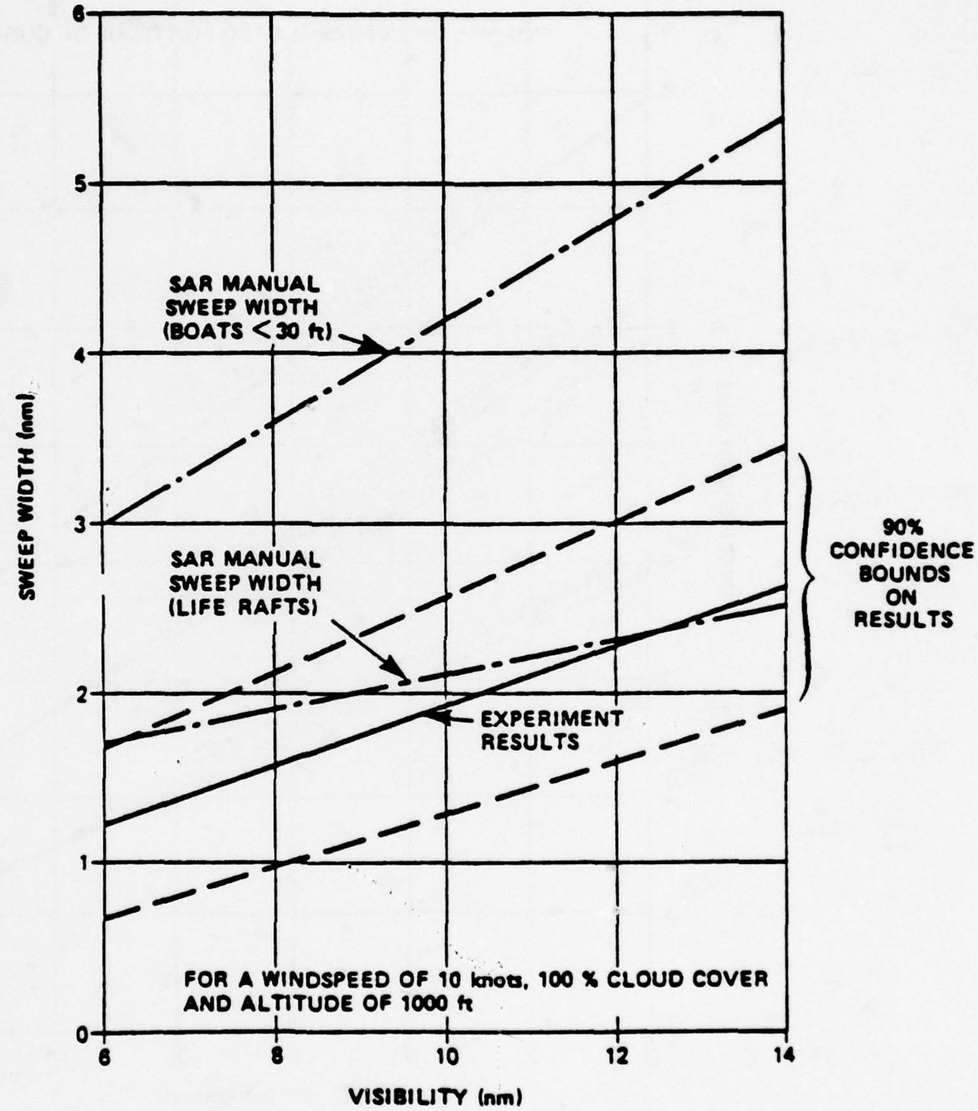

FIGURE 3-12. COMPARISON OF FIXED WING AIRCRAFT RESULTS WITH SAR MANUAL SWEEP WIDTH TABLES

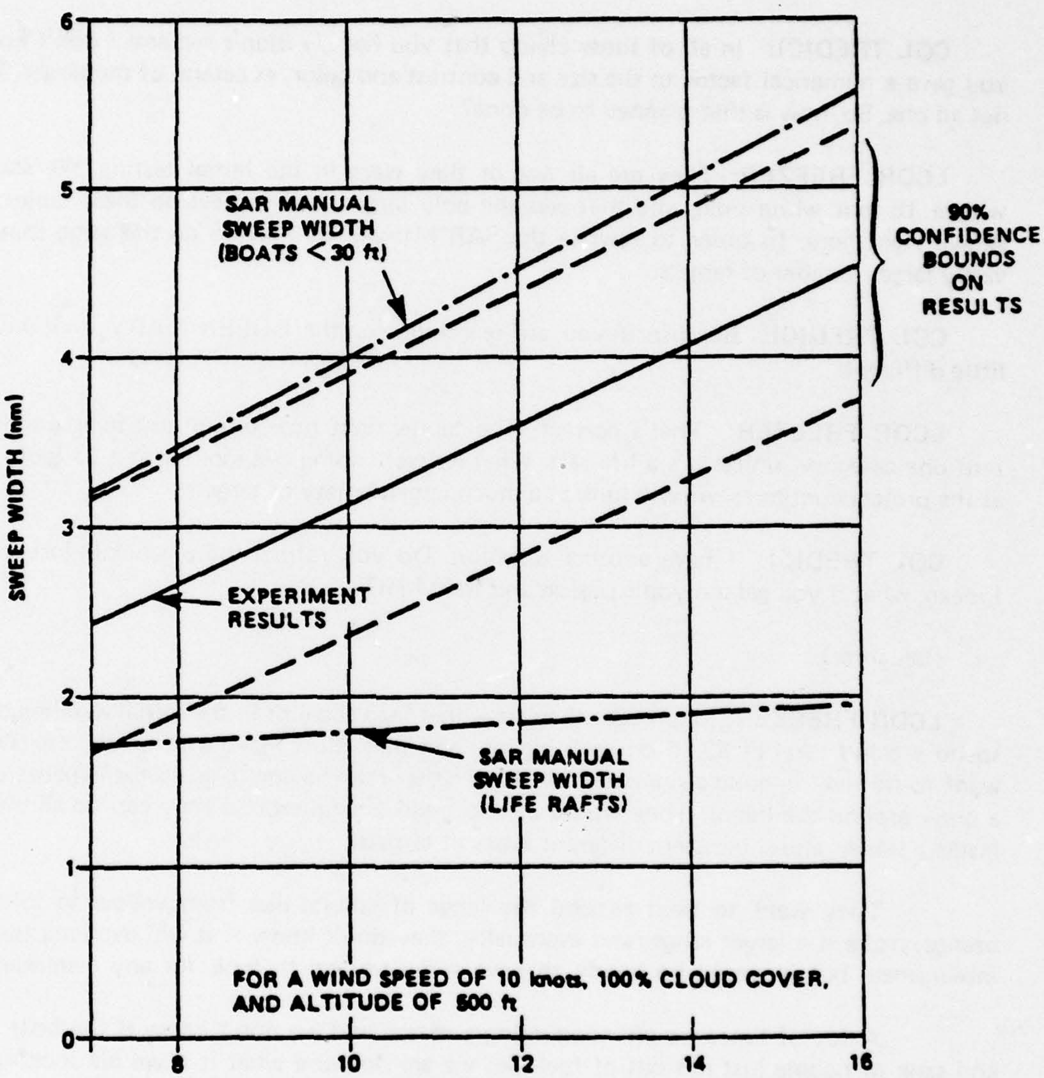

FIGURE 3-13. COMPARISON OF HELICOPTER RESULTS WITH SAR MANUAL SWEEP WIDTH TABLES

LCDR DENNIS R. FREEZER

DISCUSSION

COL TREDICI: In all of those charts that you have, I didn't see and I don't know how you gave a numerical factor to the size and contrast and color, et cetera, of the target. They are not all one. So, how is that planned to be done?

LCDR FREEZER: They are all one or they were in the initial testing. We started out with a 16-foot white boat, and that was the only target used to develop these tables that are shown right here. In order to rewrite the SAR Manual, we have to do the same thing with a vastly larger number of targets.

COL TREDICI: Because if you are searching for the QUEEN MARY, that would be a little different.

LCDR FREEZER: That's correct. The tables right now group any boat under 30 feet into one category, unless it's a life raft. What we were doing was looking at a 16-foot boat. But as the project continues, we will look at a much larger variety of targets.

COL TREDICI: I have another question. Do you refract the pigeons before you start? I mean, what if you get a myopic pigeon and train him?

(Laughter).

LCDR FREEZER: I am sure they took that into account in the initial weeding out. They spend a grand total of $2.50 on each pigeon, and they must make sure he can see. What they want to do next is build a simulator for them rather than having to go to the expense of towing a buoy around the habor. They would like to build a simulator so they can do all the training inside a trailer, and show them different types of targets.

They want to next expand the range of colors, like from yellow to international orange, make it a larger range, and eventually, they don't know if it will overload the pigeon's intelligence, but it would be handy to have some trained to look for any man-made object.

A lot of times we are conducting a search and we don't know if the boat broke up and sank or people just ran out of fuel. So, we are not sure what it is we are looking for. If a pigeon could be trained to identify anything except kelp or seaweed or whatever, it would be handy to us. We could go over and investigate.

COL TREDICI: I mention that because we had a laser project years ago in which I screened out primates, and we had to drop about 10 percent. They all had to be emmetropic or far-sighted but not nearsighted. And I wasn't aware of this at all. So, we went through and refracted them, and we found a number of them we couldn't use in the project. If we didn't know that, it would have messed things up.

LCDR FREEZER: Another question that oftens comes up along that line is: Why pigeons, because there are birds that have better vision than pigeons. But pigeons are temperamentally very well suited for this. The birds that have better vision don't like to be tied down

for eight hours straight and keep on looking. They just don't have the temperament for it.

DR. STARK: Do you have a model of these multiple factors in the search procedures so you can study the sensitivity of and the interaction of these different factors, because you have hundreds of factors involved?

LCDR FREEZER: That's what they are trying to do. They are identifying as many factors as they think reasonable to keep track of during the testing and categorize them as to how variable they really are. Some of them are human factors dependent. Some of them are weather, which we can do nothing about when we are called for a search. And they are trying to determine what the interaction is. The problem in trying to look at a large number of targets, and the reason the project is going to take quite a while, is in order to get a statistically significant number of passes- -I believe it's on the order of 700 search or detection opportunities that they had in the initial phase of testing just to come up with the limited results we have so far for a single 16-foot white boat.

DR. GERATHEWOHL: What is the maximum range that your pigeons can detect, at least out of targets which you have used?

LCDR FREEZER: The target that they were using in this testing was just an orange ball. I believe it was about 16 inches in diameter. I know during the testing they had moved it out 2000 yards. They were seeing it on the order of a mile and a half, I think.

EDITED TRANSCRIPT

HELICOPTER/SEARCH AND RESCUE

PRESENTATION BY LCDR FREEZER

Good morning, ladies and gentlemen.

I am Denny Freezer. I am the Chief of the Sensor Technology Branch in Coast Guard Headquarters Research and Development right here in Washington.

I can't add an awful lot to what the visual requirements are from the cockpit because they stay pretty much the same. Of course, we have no weapons delivery problem which eliminates about three-quarters of the job which the Navy has. However, I would like to talk about what our search and rescue mission is and how it relates to visual requirements. Search and rescue, of all of the missions of the Coast Guard, is probably the one that we are still identified with the most and the one that is most highly visible. We prosecute over 75,000 SAR cases a year. Of these, our aircraft, from a total of 30 air stations, we have 100 helicopters and 50 fixed wing aircraft. They are involved in a lot more than search and rescue, but they do take care of the search and rescue end too.

Our motto has always ben "Semper Paratus", which means always ready. That means we take off virtually no matter what the conditions are if the situation warrants, if somebody's life is in danger in particular. We have made helicopter rescues when the wind has exceeded 100 knots and actually successfully hoisted people from the deck of a boat in 100 knot plus winds.

We will go out when the conditions are zero/zero if there is any chance of getting to a boat. When we get on the scene, from a helicopter we can do a maneuver called a PATCH or a Programmed Approach To a Coupled Hover. If we can get some indication where the boat is, even if it is essentially zero/zero conditions, we will try to come into a hover next to them, and from there, assuming we can see them a little bit, move over and accomplish the hoist or lower a doctor or whatever is required.

Our present R&D projects that are attempting to help us out in this type mission can be divided into about three general areas. One of them is to develop better electronic sensors, such as FLIR, (forward-looking infrared), forward-looking radar, side-looking radar, and active gated TV.

Another is better search platforms and rescue equipment.

The third is to improve the effectiveness of our search and search planning techniques and the actual conduct of the search. The third of these is the one that I think this workshop is most interested in.

Our present searches are conducted using World War II visual search techniques and tables and so forth for setting up the searches, and they have only been updated once, and that was from data collected over 23 years ago. We are in the process now of conducting an R&D project called Improved Probability of Detection in Search and Rescue, and we are attempting to update these tables.

Ready for the viewgraph, please.

The concept of sweep width, which is a performance measure utilized by SAR mission coordinators to plan searches, is depicted in Figure 1. The sweep width is defined as the distance from the aircraft at which you will see as many targets that are beyond that distance as you will miss that are within the distance.

The shaded areas on this viewgraph on the top section indicate targets that are missed that are within the sweep, and the shaded areas on the side indicate targets that are seen and are outside the sweep width. When those shaded areas are equal, we have what we call sweep width, and that is the basis for setting up for searches. If the track spacing in use on a search is equal to the sweep width, then we call it a coverage factor of one, and our tables give indications of Probability Of Detection (POD). If you have a coverage factor of one, you should have a 78 percent probability of seeing any given target is it is in the search area and you conduct a search using a standard search pattern. If you cover that area for the second time, your cumulative probability of detection goes up to 95 percent, and up to 98 percent after three times.

The problem is: How far can you actually see a target, and have these tables been set up correctly? I have appended to my paper, which will be in the minutes, an executive summary of the interim results from this project, and the rest of my talk will just very quickly go over some of the tables and so forth that are in it. Anyone who wants the full report after reading the executive summary, the full report is available from the National Technical Information Service.

The second slide, please.

This depicts the variables that we have identified that impact on how far you can detect a target in a visual search. The ones that have the asterisk next to them are the ones that are presently utilized when we entered the tables, which, as I mentioned, are World War II vintage. Out of the primary variables, the first 11, we have varied almost all of them in the initial set of testing, and we are looking to some extent into as many of the others as we can. This project will be going on for quite some time.

The next viewgraph, please.

This, I am sure, is very hard to read from the majority of seats in here, but it is the Sweep Width's Tables from the National SAR manual, and it shows where you enter for target type and size, for visibility, for the altitude, that it is searching from, if it is aircraft, the wind speed and the cloud cover. Those are the variables that we throw in.

Then, depending on what type of target you are searching for, this gives you what the sweep width should be to give you the probability of detection I was talking about.

The problem is: Fairly often we will cover an area three or more times when we should have a 98 percent POD. It will actually turn out later on that we completely missed the boat that was in there. And it happens often enough that we know we are getting 98 percent visual probability of detection. That is the reason for trying to update these tables.

The testing is going on in the Block Island Sound/Long Island Sound area and has involved a large variety of Coast Guard boats, ships and aircraft, both fixed wing and helicopter aircraft. We use a microwave ranging system which gives us about a three meter accuracy to keep track of where the targets actually are that they are searching for and where the search units are.

Another variable that we have never officially taken into account is the fact that our units don't navigate perfectly, and all of the tables assume that navigation is perfect as far as making consecutive passes through the search area that are supposed to be offset by track spacing. We know that the track spacing isn't being maintained as accurately as it should.

The next chart, please.

Now, I will just quickly go over some of the preliminary results. These tables are from the interim report of the testing that was done last September and October. The next phase of the testing is starting later this month and will go for about another three weeks. Then after they have had time to do some more analysis, reconstruct the test and so forth, it will continue after that.

These are sweep width tables for fixed wing aircraft and for helicopters, and this shows the actual sweep widths that we got from the detection opportunities. The report itself goes into a lot greater extent than I have time to or that I understand as to the statistical analysis that is used to come up with this.

The next slide, please.

This shows the influence of search speed on sweep width for fixed wing aircraft. It is in two separate sections. One of them is visibility 15 miles and the other one is eight miles. The top one is for an HU-16, a twin-engine seaplane, and the other is for a C-130. We have documented very well here that as this search speed goes up, the probability of detecting a target from a fixed wing aircraft goes down. This is not presently a variable in our tables.

This is pretty hard to see until you have time to sit and look at it for a while. But it is the lateral range curves for fixed wing aircraft, and just some more of the preliminary results.

This is the influence of search duration on sweep width in a helicopter. This is another factor that has never been officially taken into account. We have never used this when we entered our tables, and yet everyone knows that the longer a search crew stays out, the less they are actually seeing. Here we have that for two hours search for this particular condition, the sweep width would decrease from about five miles to about two and a half miles. And, actually, the search planner in a case like this would still be using five miles, assuming that the people in the aircraft would be seeing as many targets beyond five miles as they would be missing within that.

The next slide, please.

This is a comparison of fixed wing aircraft and helicopter sweep width as a function of wind speed and visibility, and it attempts to show what the - - some of the other tables show the variation between what we are actually experiencing and what the present tables in the National SAR manual show.

Next, please.

This is a comparison of fixed wing aircraft results with the SAR Manual sweep width tables. The tables in SAR Manual now lump every boat over 30 feet in one category. For instance, here we are looking at a 16-foot boat, the actual results we got, labeled experimental results, fall almost on the line which the tables use for a life raft, and the table value for any boat under 30 feet is way up here. So, actually, now when we conduct a search, we are setting up our search parameters for a 16-foot boat using this guideline, we actually should be using just about what the tables say for a life raft.

Next, please.

This is a comparison of helicopter results with the SAR Manual sweep width tables. Again it is a similar type situation. We don't actually experience the detection probability that the tables say that we should.

Next, please.

Here is another project that I would like to show about a five-minute film on. Usually when I bring this up, people think that I am kidding, but we actually have had tremendous results so far. This depicts a container with three pigeons in it, and it is suspended from the bottom of the helicopter. The direction of flight is shown. The container is divided into three sections, and in each of these is a pigeon that is held in position. The little circle in the front designates a key that he can peck when he sees the target. So, as the helicopter is flying along, the pigeon on the right starts pecking, that shows he has a target in view. Each pigeon sees about a 180 degree sector. So, there is overlap. What the pilot does is turn to the right until the pigeon on the left side starts pecking. Then he knows that the target is in the overlap area or almost directly ahead. Believe it or not, the aircrew - - I will show you this film and it shows some of the training. But even with the aircrew having the advantage of having put the target in the water themselves, the pigeons don't know when to start searching and when to guit. They just never quit. But they go out. The pilots have the crewmen throw an orange ball out of the helicopter. They fly several miles away, turn around and come back. All this time the pilots are taking it easy and so are the aircrew. They know they don't have to search until they get back into the vicinity, and they they start looking intently, and 84 percent of the time the pigeons beat them to it. They have been searching since they left their home base. Not only that, many, many times during the initial testing these pigeons will be pecking away like crazy. They will fly over the target. These two will stop and this one will pick it up, and nobody in the helicopter has seen it yet. And there have been cases where they had to make four or five passes before the pilot could find his own target again. In the meantime, the pigeons are taking turns pecking, depending on which one can see it.

VISUAL OPERATIONAL CONSIDERATIONS IN VERTICAL/SHORT TAKE-OFF AND LANDING (V/STOL) AIRCRAFT

Major Jay C. Lillie, USMC

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WARMINSTER, PENNSYLVANIA

V/STOL combines the abilities of Fixed Wing and Helicopter Aviation. At present V/STOL does its mission but at a price; (1) it can hover but not at max payload, and (2) there is little room for fighter weapons systems or cargo carrying capability.

The Harrier (AV8A and proposed AV8B) is the only operational V/STOL aircraft in the free world and the only one forecast in the U. S. forces through 1990. Therefore, the Harrier will be used for my point of reference to V/STOL problems, today and in the future.

This presentation lends itself to analysis by phases of flight and the conditions acting on those phases. The primary phases of flight are Take-off, mission accomplishment (conventional aerodynamics) and Landing. The primary considerations to flight are where flight starts and stops, whether on land or sea and is it day or night.

The conventional flight mode is similar to any high thrust to weight jet attack aircraft. The problems of matching the proper on-board sensors to the visual and oral perceptions both in and out of the cockpit become a human factors problem.

It is during Take-offs and Landings that V/STOL attracts attention. The Harrier makes three types of take-offs: (1) Conventional; 2 to 3000 ft/160 kts. (fast acceleration like a soft catapult shot); (2) Short Take-Off; 500 to 1000 ft/65 to 120 kts. (fast with perceptions of crosswind and aircraft attitude as it lifts off very important.); (3) Vertical Take-Off; Straight up with forward acceleration beginning about 75 to 100 ft. Crosswind, rate of acceleration (airspeed increase) and altitude above the ground are extremely important. This maneuver is done almost totally visual external to the cockpit instruments.

There are four basic types of landings:

1. **Conventional** - Which has a shallow glide slope, fast speed (155 kts.), low sink rate and long roll out, 8000 ft. minimum runway required. Problem is to stay out of the trees on approach and not land short or long.

2. **Slow Landing** - Normal glide slope and speed (110 to 130 kts.) but more cockpit workload - **4000 ft.** minimum runway required.

3. **Rolling Vertical Landing** - Pilot must decelerate the aircraft at an altitude of 100 to 200 ft. from 180 to 60 kts. ground speed then descend at 60 kts. the final 100 ft. to the landing area. It requires 500 ft. of runway or road. This technique is used when the landing surface may contain rocks or gravel harmful to the engine. Crosswinds must be monitored throughout the landing all the way to touchdown.

4. **Vertical Landing** - Pilot must decelerate as in the Rolling Vertical Landing **except** that his final speed is **0 kts.** and he positions himself over the intended landing spot at 50 to 100 ft. By reduction of power he lowers himself to the landing spot watching for forward/aft and left and right drift. Crosswind is again **very** important on the deceleration phase.

I have talked about land-based operations but the goal for the Navy of the future is to have V/STOL aircraft capable of working off ships as small as a Spruance Destroyer.

Today we have two types of V/STOL platforms. The long deck such as the CV, LHA, and LPH permit a short take-off and vertical recovery for the Harrier. Ships such as the LST, LPD have platforms only large enough or safe enough for vertical take-offs and vertical landings during **daylight.**

Some of the constraints of CV's, LHA's and LPH's are: On short take-offs the deck is narrow and offers little or no abort. The acceleration is rapid and decisions must be made in two or three seconds maximum. On vertical take-offs there is no line feature to assist with visual perceptions of crosswind so the workload increases.

All landings are vertical which is no problem on a large ship durng the day. At 50 ft. above the ship deck it is sometimes difficult on small ships to see enough of the ship to maintain your stable position with no drift. The sea around the ship is of no visual value and can give false sensations of movement to the pilot. At night the transition from 180 kts. to zero relative to the ship is a real challenge. All aids must be used; aircraft sensors (Tacan), oral (carrier controller) and visual (mirror approach system) to name a few that must be integrated by the pilot. The transition from instruments to external visual perceptions begins about 500 ft. from the stern. The rate of closure must be checked so that a stable position is achieved over the landing point. Ship wind over deck can vary by 40 to 50 kts. and there are no lights forward of the landing area so if you drift too far forward you are forced to try a wave-off which at night would be extremely difficult at that airspeed. It might be stated that at present **night vertical take-offs** are generally not done because the pilot lacks good visual references as he leaves the confines of the ship.

The second type of aviation ship has a platform for vertical take-offs and vertical landings (example LPD, LST). Besides the problems already discussed the small ships also have more deck movement in moderate or heavy seas which reduces the safety margin. These ships are used during the day in good weather conditions only.

Some thoughts:

1. The first generation V/STOL needs better human factors engineering especially in heads up display design.

2. There may be definite advantages to having a helmet mounted heads up display for take-offs and landings.

3. Pilot visual perceptions inside and outside of the cockpit will be the prime contributor to take-off and landing safety in V/STOL throughout the 1980's.

EDITED TRANSCRIPT

VISUAL OPERATIONAL CONSIDERATIONS IN VERTICAL/SHORT TAKE-OFF AND LANDING (V/STOL) AIRCRAFT

PRESENTATION BY MAJOR LILLIE

Good morning. I want to talk about V/STOL. For those of you who don't know, as has already been mentioned, it is vertical short takeoff and landing. It combines the ability of presently fixed wing aviation and helicopter aviation.

At present, V/STOL does its mission but at a price. It can hover but not at a max payload equivalent to a helicopter, and there is little room in the present vehicle for advanced systems because of their weight. We also have very little cargo carrying capability. So, you can have V/STOL, but you must pay a price in both hover capability and also the payload that you can take aboard.

The HARRIER, which is the AV8A and the proposed AV8B which will be a follow-on, are the only operational V/STOL aircraft in the free world and the only one forecast for the U. S. forces through the 1990's. Therefore, the HARRIER will be used for my point of reference to V/STOL problems.

This presentation lends itself to analysis by phases of flight and the conditions acting on those phases. The primary phases are, of course, the takeoff and then mission accomplishment, which is conventional aerodynamics, and then the landing phase. The primary considerations to flight are where flight starts and stops, whether on land or sea, and is it day or night.

The conventional flight mode is similar to any high thrust to weight jet attack aircraft. As the Commander discussed earlier, the problems of matching the proper on-board sensors to the visual and oral perceptions both in and out of the cockpit are human factors problems. It is during the takeoff and landing phase that V/STOL attracts attention from those who see it and also from those who have to utilize it as a combat vehicle.

The HARRIER makes three types of takeoffs - - basic types. There are actually more take-offs that it has to make, but it differs from either helicopter or jet, normal jet conventional aircraft, which make a standard type of takeoff - - one type of takeoff and one type of landing. We make several types which require, therefore, more procedures to be learned and more chances for error to enter into the picture.

We have the conventional mode which requires 2,000 to 3,000 feet to take off, which is just like any airline or jet aircraft takeoff. You break ground at approximately 160 knots. The acceleration is quite fast. We liken it to a soft catapult shot that you would experience off a carrier. So, in this regard you are required to make very quick responses to what you see visually in the cockpit and external to the cockpit. Acceleration can get your attention, definitely, and it doesn't give you all the time to make these quick perceptions as to what you see as far as instrumentation.

The second type of takeoff is called the short takeoff. By moving equipment in the cockpit, you are able to take off now in 500 to 1,000 feet of ground roll, and you break the ground at somewhere between 65 and 120 knots. This again is very fast. You can imagine the ground roll of 500 to 1,000 feet, and sometimes getting up to 120 knots. It happens very quickly, in the neighorhood of about five to six seconds from the addition of power until you are in the air. So, you have to perceive what is going on, especially with crosswind and with the aircraft attitude as it breaks the ground; to perceive what your predicament is and if it is controllable.

The last mode of takeoff is called the vertical takeoff in which you, of course, take off straight up just as a helicopter would. At about 75 to 100 feet in the air, you then start the transition to forward flight and gradually accelerate to a flyable airspeed in which conventional aerodynamics take over. Crosswind, rate of acceleration - - in other words, your air speed increase -- and the altitude above the ground are extremely important. Obviously, altitude above the ground is extremely important. This maneuver is done almost totally visually with very little cockpit information absorbed. It is a feeling that you have to come up with and it is taught during your initial phases of training. The heads-up display unit, that was mentioned earlier and diagrams were shown, is the primary visual means of transmitting to you instrumentation in the cockpit. You don't have time and you cannot look inside the cockpit for inputs as far as instrumentation.

There are four basic types of landings. We make a conventional landing which is very similar to other kinds of fixed wing aviation, except that it's quite fast. We have a very small wing and it's similar to, I guess, the 104 in the Air Force; something that lands very fast. We have a very shallow glide slope in comparison to most aviation because our landing gear is not stressed for normal conventional landings. The speed is fast, about 155 knots. We must have a low sink rate and a shallow glide slope, and a long roll out of about 8,000 feet is required. The problem is to stay out of the trees on the approach. In other words, have a very flat glide slope and yet still land not short or not long, but right in the intended landing area. It is the perception of the landing area that is sometimes difficult.

The second type of landing is a slow landing in which you have what would be close to a normal glide slope, about a three degree glide slope which is normally used in carrier aviation. Your speed is now between 110 and 130 knots, and the cockpit workload builds up because you are using mechanisms inside the cockpit to slow your speed down, and it requires less roll out on your landings, only about 4,000 feet.

The third type of landing is called the rolling vertical landing. The pilot in this maneuver must decelerate the aircraft at an altitude of about 100 to 200 feet. He decelerates it from 180 knots to 60 knots. Then at that altitude at 60 knots, he continues to bring it down the last 100 feet to land at a forward speed of 60 knots. This requires only about 500 feet of ground roll once he lands on the runway or, as we do in the Marine Corps, either on grass or sometimes on a road so that we don't have to be tied to utilizing existing runway structures.

Crosswind again is very important, and as I will show you -- it's somewhat difficult to see in this picture, but you might be able to pick it out. Although there are a lot of sensors in the airplane, the HUD itself, which lets him see through the wind screen, shows him side slip which helps him define crosswind and how the crosswind is affecting the airplane. With an excessive

amount of crosswind at slow speeds, he sets himself up aerodynamically to depart the airplane at crash. So, it is highly important that he keep that in his scan.

In the front here we have a very sophisticated piece of equipment which is hard to see in this picture, but it is a standard weather vane. And I personally would care little about all the rest of the instrumentation in the airplane, but this small weather vane which sits out here and is probably a $ .50 to a $2.00 item purchased out in the civilian world or probably a $100 item if purchased by the government, strictly shows you the relative wind as it affects your airplane. And as long as you line that arrow up with the fuselage, you are going to live.

The last type of landing is the vertical landing. Of course, it is the one that draws all the attention and is mind-boggling to those who haven't seen the HARRIER perform. You decelerate the airplane as in the rolling vertical landing at about 100 to 200 feet above the ground from 180 knots, but this time you don't slow down to 60 knots, but you slow down to zero, and then at 100 feet into the air, you stabilize so that your forward and aft drift and left and right drift are stable. You look out and you must perceive visually at this time. Although some helicopters have the mechanism in their systems to stabilize at one point completely automatically, the cost and weight penalties involved in incorporating that system into the HARRIER have precluded doing so at this time. Also, because the HARRIER lives on a small thrust to weight margin, that keeps you alive as far as keeping you in the air, and the stability factor that is somewhat tenuous, at present it has not been incorporated. So, the pilot is the one that flies it. It's a seat of the pants airplane. Because it is a seat of the pants airplane, you have to visually interpret what you see as far as forward/aft drift and left to right drift. When you see that it is stabilized, you reduce power and slowly descend to the landing area. Again, crosswind is very important on the deceleration phase, especially around 60 knots, as you pass through 60 knots approaching zero. Once you get to below 30 knots, then the aircraft flies very similar to a helicopter.

I talked about land based operations, but the goal for the Navy and the Marine Corps of the future is to have V/STOL aircraft capable of working off ships as small as the SPRUANCE destroyer.

Could I have the first viewgraph, please?

We have two types of V/STOL platforms. Of course, this is a schematic or drawing of an envisioned platform for vertical STOL aircraft. It gives you a full deck in which you may make a running takeoff or the short takeoff and come back and make a vertical landing. You have a large amount of deck space. Typical of this would be our present conventional carrier, the LHA, the LPH. They permit the short takeoff and a vertical recovery.

The second overhead which I have depicts the other type of ship which permits only vertical takeoffs and vertical landings. You have one small area. Presently, although it's feasible, I certainly wouldn't want to do it utilizing the HARRIER for landing on the back of a small platform ship such as this. We can land though on ships such as an LST, an LPD which have platforms about three times that size. But we do those only during daylight hours and when the conditions out are strictly visual.

Some of the constraints of CVs, LHAs and LPHs are that on short takeoffs the deck is extremely narrow. This happens to be the USS ROOSEVELT and it gives you a relationship of the F-4 and the HARRIER in size. This is the back portion of the carrier. Again, you can see the wind vane on the front of the aircraft. Here the pilot is lining up 500 feet from the bow, positioning himself for a deck run of 500 feet to become airborne. This is a position showing the front portion of the carrier in which he will make his run down this particular line off the front. This happens to be showing an aircraft coming in to land on the forward portion. But what I am interested in here is showing you the deck run for the short takeoff that he will accomplish. Again, he is back there positioning himself on that line ready for takeoff. He is given the run up, the signal. He is ready to go. And there he smokes off the front. Acceleration is very rapid and decisions must be made very quickly. You have about two or three seconds from the time he adds power before you can stop it without going off the front. So, you have to perceive what is in the cockpit as far as your power performance and what you have available and whether you are going to make it. Your only alternative is to eject if things aren't going correctly.

Vertical takeoffs: There are no line features. You can see, if this aircraft had made a vertical takeoff from this position and was now ready to accelerate out, as he accelerates he must again be worried about crosswind. And without a line feature, meaning trees or a road, woods, whatever, he has difficulty interpreting his rate of crosswind component and how much he is drifting, and he has only that yaw vane. So, as soon as he leaves the deck, he has only water to look at. Each wave looks the same and can give him very false sensations. A vertical takeoff during daylight can be done and it is not very hazardous. During nighttime or during bad weather, foul weather conditions, it is extremely difficult.

All landings are vertical on the ships, and there is no problem on the large ship at day. You come in at about 50 feet over the deck. On smaller ships, of course, that's much more difficult. As you can see -- from this position he can't see the edge on either side. All that he can see is water. Believe it or not, all he is flying on is this crane. He can see the deck, approximately this position forward. So, all of this he is blind to. There is a man up in the tower talking him down and telling him, "Yeah, you look pretty good. Come on. Bring it down". Only when he is down close to the deck will he actually start to pick up a field of view of the rest of the platform he is landing on. Helicopters, of course, have plexiglas underneath, the chin bubble, and therefore they can look down through that chin bubble to see movement, relative movement, which is very important as far as cancelling out drift.

Again, I will mention one more time, watching the sea can be very, very confusing, and it gives you a sensation of movement if you look at the water that is really not there.

At night, the transition on approach, he does the same maneuver. He must use instrumentation all the way down as he approaches from straight aft from about, oh, two miles out until he gets to a position about 500 feet from the stern. He does it on instruments. As he gets to that point approximately 500 feet from the stern, he must transition from instrument scan through his Head-up Display to looking at the back of the aircraft carrier which is lighted, but lighted very dimly; something about like this room. And he must perceive his rate of closure visually on that ship, for if he goes too fast - - he goes to the forward part of the ship which is unlighted. Therefore, he is in an unlighted area and he is just about out of ideas. It is very difficult to wave-off in that situation without crashing into the water. So, he must be very careful of what he does to watch and perceive how rapidly he is closing on the ship and keep it under control. Well, the wind over the deck as the carrier moves through the water can some-

times vary by 40 to 50 knots. So, he has to be aware of how the ship is moving through the water, and how much wind there is over the deck in order to calibrate how fast he will close on that ship when he gets within 500 feet. He must use all the aids at his disposal.

Could I have the next viewgraph, please.

Normally he has the aircraft sensors and aids such as TACAN and Heads-Up Display. He uses the ship's carrier radar controller and also the visual aid, mirror system that is located along the edge of the deck to give him glide slope information. I might mention some of the sensors that he is using in the Heads-Up Display. Of course, these are four different pictorial descriptions. But we will take this one, for instance. On this side these dots are the angle of attack. He must be very concerned about the angle of attack the aircraft approaches, maintaining control of that. Over here is his rate of descent. Each one of these dots represents 500 feet per minute rate of descent. He is presently coming down at roughly 1200 feet per minute. Of course, here is his heading control. Here is side slip at night, the method of telling whether he's got a large crosswind or not and how it is affecting him. Here we are reading air speed. And over here we are reading the altitude. Those, of course, are constantly changing.

Very important, the Heads-Up Display, as I will mention later, is a real God-send to the pilot. It can be improved. This is early technology. It is being improved as will be discussed with other performers later in this workshop.

The transition from instrument to external visual perception begins about 500 feet, as I said before. That's where hopefully everything is under control at that time. Again I might mention that presently we do not do night takeoffs because of the problems associated with visual perception when it is dark. Being able to keep all the information sorted in your mind quick enough, it's almost too much to do, and it's not a safe maneuver.

The second type of aviation ship that I mentioned that has a platform for vertical takeoffs and landings is the LPD or the LST. Besides the problems already discussed about small ships, we must discuss the fact that they are also more prone to movement during high sea states, and the more the deck moves, the more you want to try to chase it in your airplane. So, it becomes much more difficult on a small ship.

I would like to show you a very short movie which will show you a helicopter, a LAMPS helicopter, taking off from the back of a small platform ship. It shows the stability problems. This is perfect sea state. This aircraft will take off and turn out to the side, a difficult maneuver for the HARRIER to accomplish. It can be accomplished like this helicopter will do, but it is difficult. Then it will show you the pilot's view of the ship, and you will see that he is not very far away, maybe half a mile or so, and yet the ship looks extremely small. Then it will show you an approach as you are in the cockpit to that platform and what you would actually be seeing in the pilot's eye. The it will show you from the deck what it looks like on your approach. And you will see that as he gets in close to the deck, there are some stability problems, and he tries to chase it. And the helicopter is far more responsive than the AV8 is. So, his problems are easier; yet he is still chasing the deck. He also may come down and hover five to ten feet off the deck, which the HARRIER must stay during the terrific windblast and the possibility of that windblast being reflected off the landing platform back up into his intakes, thereby giving him a lot higher temperature in his engine, he must remain at 50 feet to stabilize, which thereby reduces his visual perception of what is underneath it. All he can see normally is water. So, he

must remain at 50 feet. Therefore, it's even more complicated because of his high altitude, deciding whether he is stable or not. Then he is allowed to come down after he is stable, then come down and briefly pass through that 50-foot regime on his way down to the landing.

Could we roll the film, please.

Remember that V/STOL or the HARRIER is a first generation V/STOL. We need a lot better human factor design in the cockpit to help out the V/STOL pilot, especially in the Heads-Up Display. There may be definite advantages in having a helmet mounted display because of the fact that V/STOL is not looking straight ahead like most fixed wing aviation but is required to look sideways on his landings and takeoffs. So, therefore, we need something that will allow him to look down and have a display on his visor or to give him the inputs he needs as far as what is happening in the cockpit. Pilot visual perceptions inside and outside of the cockpit will be the prime contributor to takeoff and landing safety in V/STOL throughout the 1980's.

And don't get me wrong. I think this is the greatest airplane in the world. Even though I have given you the deficiencies, I would go out and fly it in a minute. It is probably the second most fun thing I can think of.

MAJOR JAY C. LILLIE

DISCUSSION

DR. O'HARE: You probably have some accident analysis data you might tell us about. There have been a lot of accidents with this particular aircraft.

MAJOR LILLIE: That's a sensitive point, obviously. I never crashed one. And in this last squadron I was with, we had eight pilots in the squadron with over a thousand hours and none of them had ever crashed either.

The crash analysis is a difficult thing to discuss, for one thing, because this plane is so different in its mission. Normal crash analysis is done, and this is my own view, but you analyze crashes on the basis of 10,000 hours of flying. What is your rate every 10,000 hours you fly these airplanes? How many crashes are you going to have every 10,000 hours? It takes us a lot of time to generate 10,000 hours of flying, yet we pass through the most critical regimes, the takeoff and landing. We are more prone to having situations develop that will cause an accident. The aircraft is good. It's a taxing airplane, but it's nothing that can't be handled with a proper amount of training and a proper pilot behind the controls.

DR. O'HARE: You wouldn't attribute it to visual problems?

MAJOR LILLIE: You can do a lot better in the human engineering standpoint to give the pilot better sensors; he's doing a lot of it now visually as far as ground movement.

DR. GERATHEWOHL: This is a subsonic aircraft; isn't it?

MAJOR LILLIE: Basically subsonic. It is transonic.

DR. GERATHEWOHL: Its maximum speed is just about 600?

MAJOR LILLIE: Yes, that's correct.

CDR ROACH (Navy, Bureau of Medicine & Surgery): Have they tried to use a closed circuit TV camera in the bottom of that aircraft so they can see the deck coming down?

MAJOR LILLIE: I talked to McDonnell Douglas who will make the follow-on airplane, if we get one, and they have already thought of possibly putting small sensors, visual cameras, on the wing tips, that could be slaved to a helmet-mounted display. Just as soon as the head actually gets below the cockpit rails he would end up with being able to see underneath. For all this you pay a weight penalty, and especially a dollar penalty.

DR. NELSON: Would those TV cameras be presenting a stereoscopic display?

MAJOR LILLIE: That's what he said it would be, hopefully.

DR. CHISUM: You would be making a vertical landing?

MAJOR LILLIE: You come in to a point roughly 50 feet over that platform.

DR. CHISUM: So, you have to maintain some forward speed?

MAJOR LILLIE: Forward speed right up to that point and then stop it and then maintain it right over the platform at about 50 feet or so, and then when you feel that you are stable and you are right over the center, you would descend; just reduce power and come right down to the landing point.

DR. COHEN: The HARRIER is basically, as you have described, a VFR aircraft. Obviously, attack operations should be at the very least all weather.

MAJOR LILLIE: It would be desirable. But, again, any time you do that, you pay a penalty.

DR. COHEN: The question is what prospective is there for improving avionic displays for getting the HARRIER to be an all weather type aircraft or a day/night aircraft?

MAJOR LILLIE: Probably the best example at present in the fleet is the A-7 with a lot of sensors on board, he finds his workload is extremely taxing.

The A-6, which is the Navy's and Marine Corps' best weapons system for all weather attack, is a very complicated, two-person aircraft that does the job fairly well.

DR. COHEN: So, at this point there is no prospective for the HARRIER to be anything but a daytime aircraft in fair weather operations; is that correct?

MAJOR LILLIE: There will be advances made. It will not be designed as an all weather aircraft. It will have limited capabilities during foul weather.

DR. COHEN: At nighttime?

MAJOR LILLIE: At nighttime also.

ADVANCED DISPLAY CONCEPTS

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INTRODUCTION

The Army, Navy, Air Force and NASA are all developing advanced airborne display systems for the types of aircraft envisioned in the last two decades of this century. Some of these applications are fixed wing, rotary wing, V/STOL, space shuttle and ground stations for the RPV. The development of these systems really involve three basic technologies, system integration, equipment design and human factors. (Figure 1).

System integration and Human Factor while very interesting subjects do not appear appropriate for a Workshop on Visual Needs.

Equipment design can be further subdivided into electronics and display elements. The electronic equipment again appears inappropriate for this gathering.

Therefore, I would like to confine my remarks this morning to the display technology itself and how it shall be used in the 1980's and 1990's.

BACKGROUND

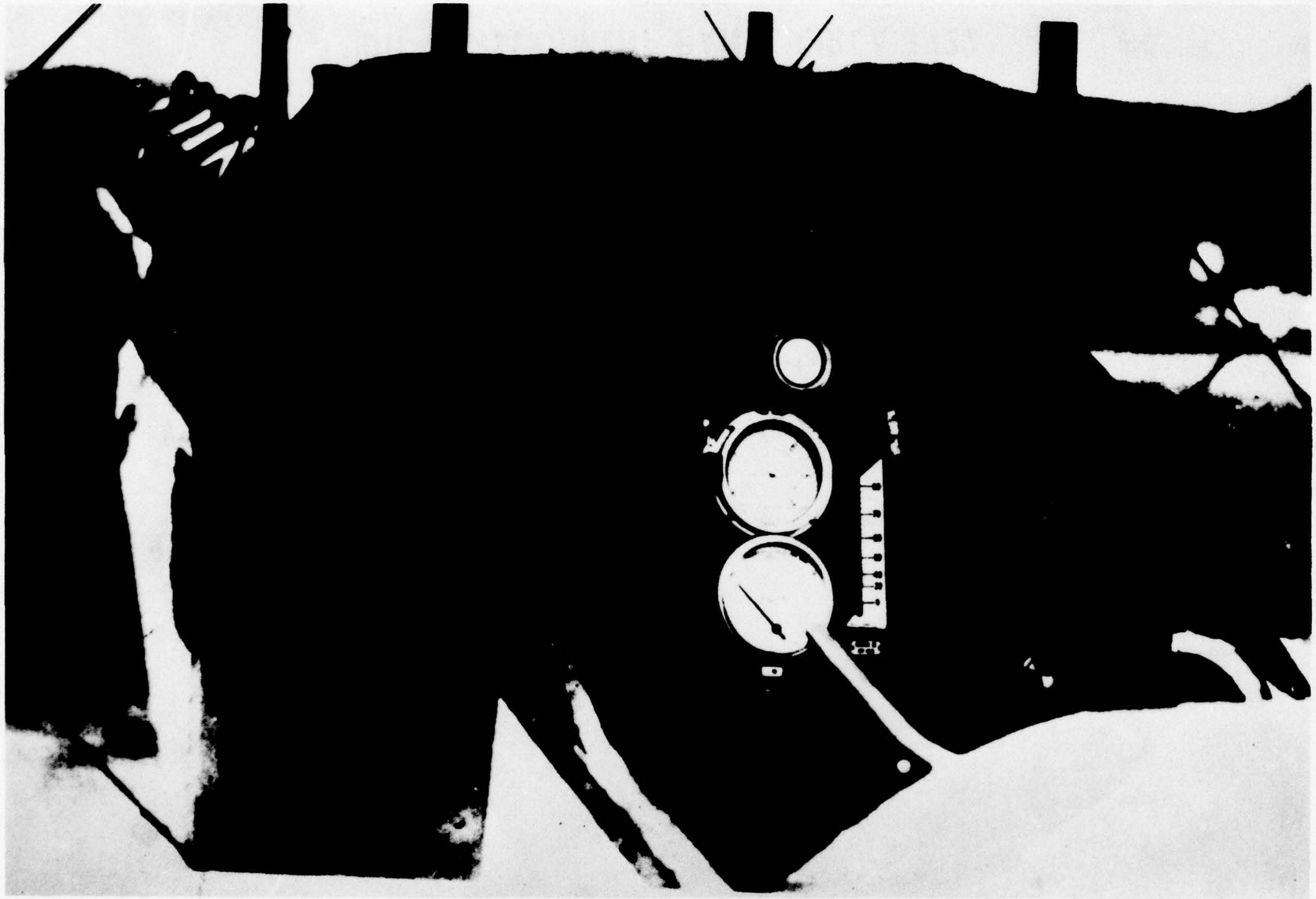
Throughout the history of aviation the trend has been to add an electro-mechanical indicator or incandescent readout for each additional data requirement of the pilot. The incorporation of radar to airborne platforms introduced the cathode-ray-tube (CRT) to the pilot station. As it became obvious we were running out of instrument panel space the designers turned to the CRT to satisfy the increased need for specialized information as the performance of the aircraft and its avionics and weapons increased (Figures 2-10). As the processing capabilities of the aircraft subsystems increase even the CRT will become unsuitable because of its size, weight, power and frailty.

Today's, and more importantly tomorrow's, military aircraft and associated displays must be extremely flexible to cope with this increased data caused by the wide variety of weapons and weapon delivery options, active and passive countermeasures, enemy weaponry, and complex pilotage problems. (Figure 11). The need for increased capabilities has driven all three services and NASA to investigate new technology to replace the existing devices, the cathode ray tube (CRT), incandescent readouts, and electromechanical displays.

BASIC TECHNOLOGIES

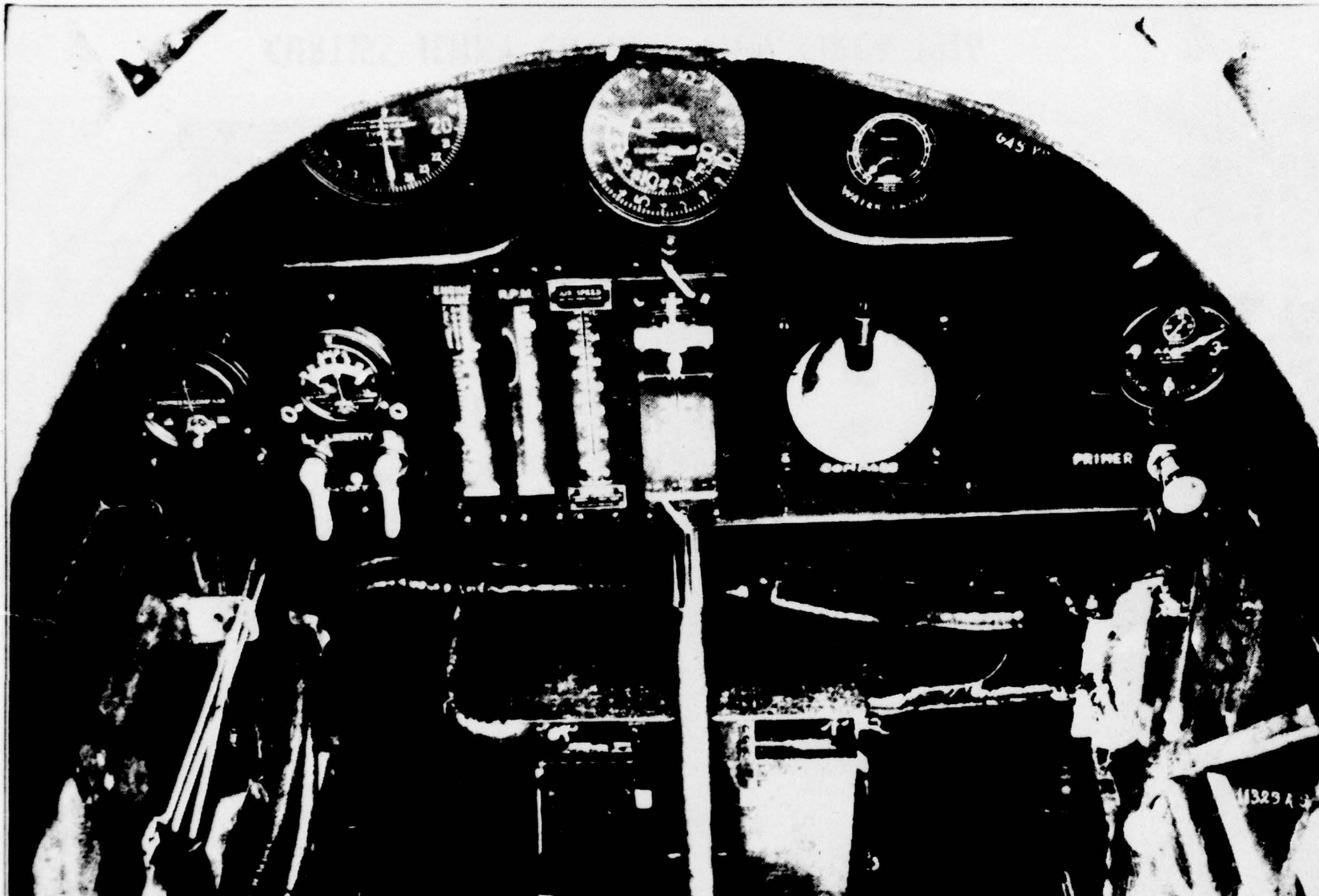
- SYSTEM INTEGRATION
- EQUIPMENT DESIGN
- HUMAN FACTORS

FIGURE 1. THREE TECHNOLOGIES



CURTISS JENNY COCKPIT VIEW CIRCA 1916

FIGURE 2

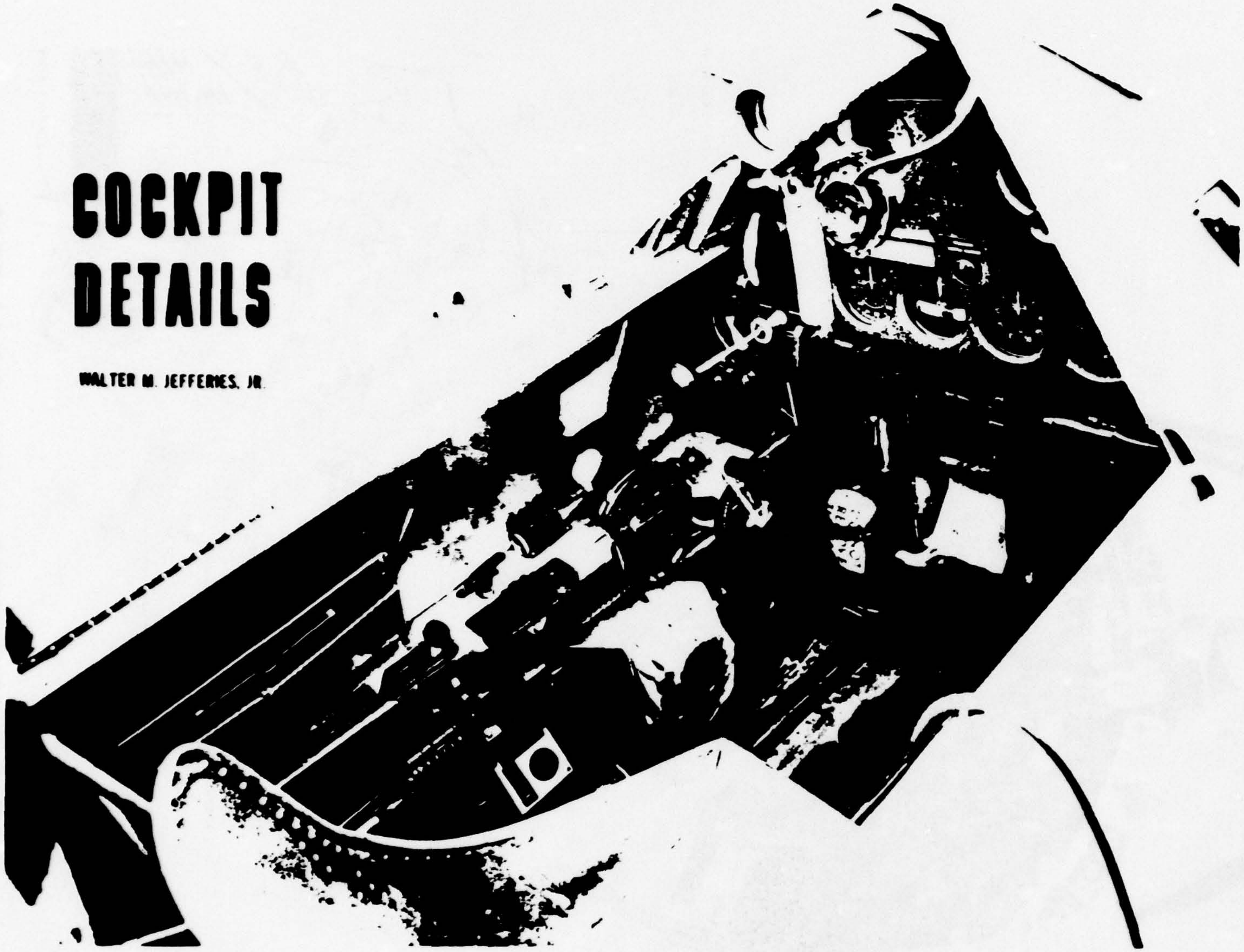


DH-4 INSTRUMENT PANEL CIRCA 1922

FIGURE 3

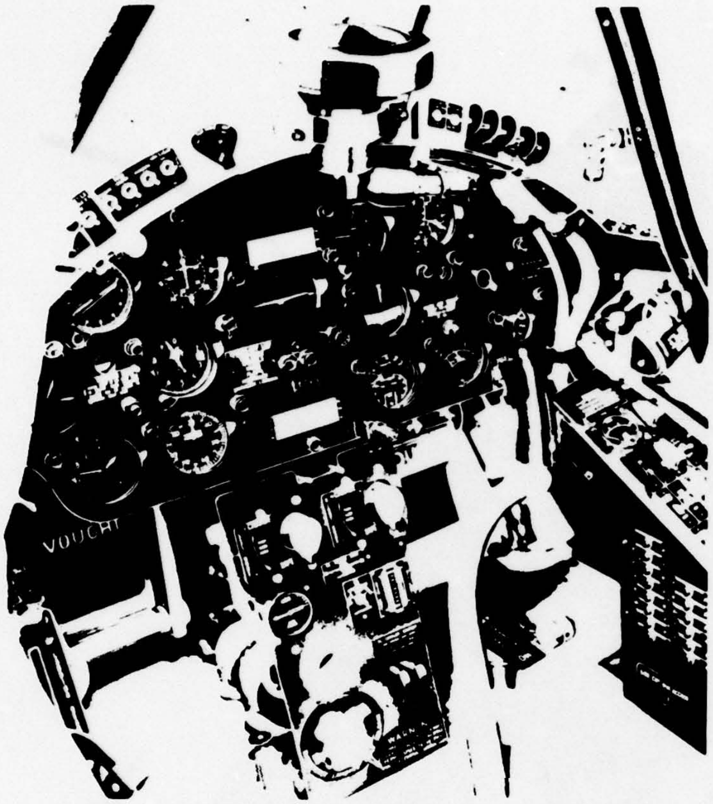
COCKPIT DETAILS

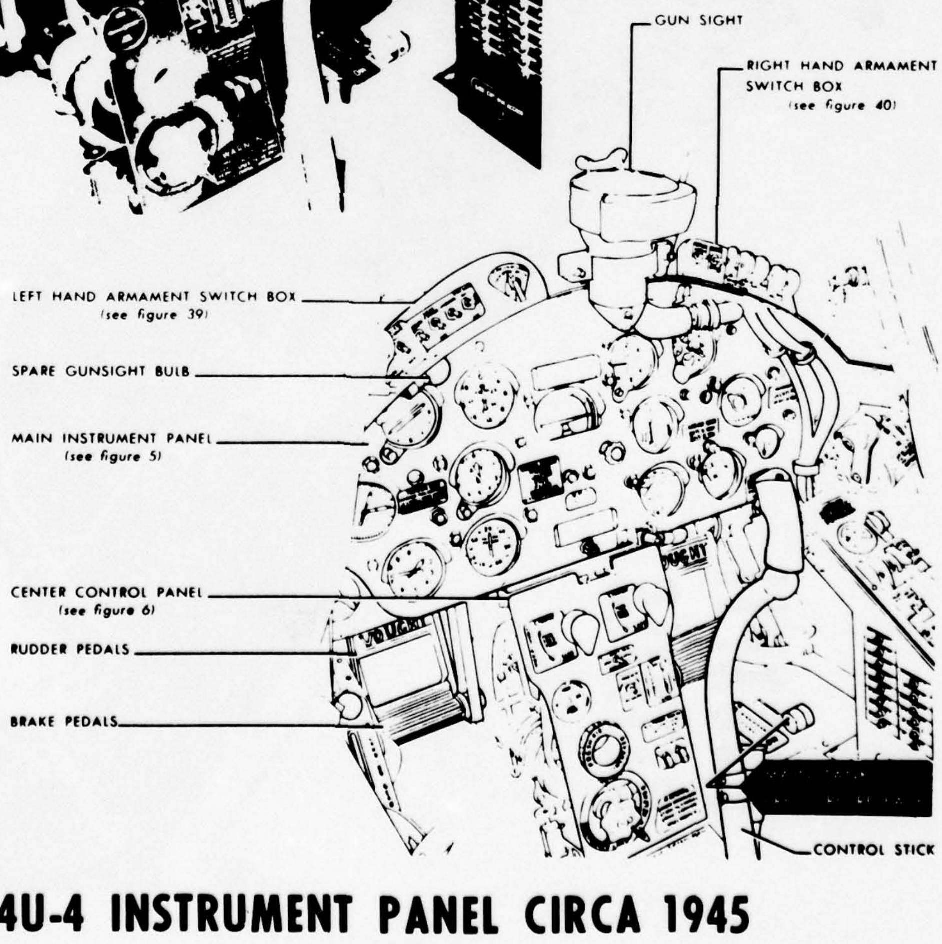
WALTER M. JEFFERIES, JR.



F3F-1 COCKPIT VIEW CIRCA 1935

FIGURE 4

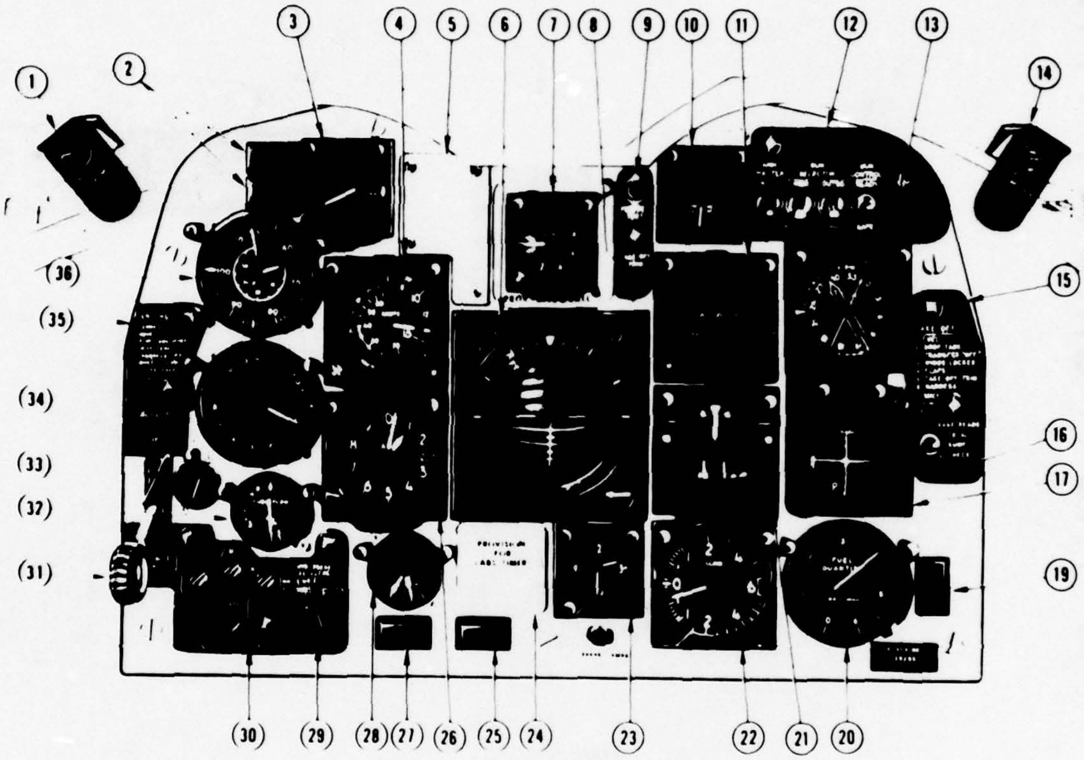




F4U-4 INSTRUMENT PANEL CIRCA 1945

FIGURE 5

INSTRUMENT PANEL
AIRPLANES 139281 THROUGH 139315



1 MACH TRIM SWITCH
2 ENGINE FIRE DETECTOR WARNING LIGHTS
3 ANGLE OF ATTACK INDICATOR
4 AIRSPEED INDICATOR
5 (DELETED)
6 ATTITUDE INDICATING GYRO (VGI)
7 ACCELEROMETER
8 TAKE OFF TRIM INDICATOR
9 FIRE DETECTOR TEST SWITCH
10 CABIN PRESSURE ALTITUDE INDICATOR
11 AN/ARN-21 RANGE INDICATOR
12 GUN CONTROL PANEL
13 RADIO MAGNETIC INDICATOR
14 YAW DAMPER SWITCH
15 TAKE OFF CHECK LIST
16 FUEL GAGE READS SWITCH
17 COURSE INDICATOR
18 (DELETED)
19 LOW FUEL WARNING LIGHT
20 FUEL QUANTITY INDICATOR
21 TURN AND BANK INDICATOR
22 RATE OF CLIMB INDICATOR
23 CLOCK
24 PROVISION FOR LABS TIMER
25 WINDSHIELD ANTI-ICE OVERHEAT LIGHT
26 ALTIMETER
27 FLIGHT CONTROL PRESSURE WARNING LIGHT
28 HYDRAULIC PRESSURE INDICATOR
29 HYDRAULIC PRESSURE SELECTOR
30 LANDING GEAR AND FLAP POSITION INDICATOR
31 LANDING GEAR CONTROL
32 FUEL FLOW INDICATOR
33 OIL PRESSURE INDICATOR
34 TAIL-PIPE TEMPERATURE INDICATOR
35 LANDING CHECK LIST
36 TACHOMETER

FJ-4B-1-00-23D

FJ-4 INSTRUMENT PANEL CIRCA 1957

FIGURE 6

PRESENT SYSTEM—A6 INSTRUMENTATION

9796-2

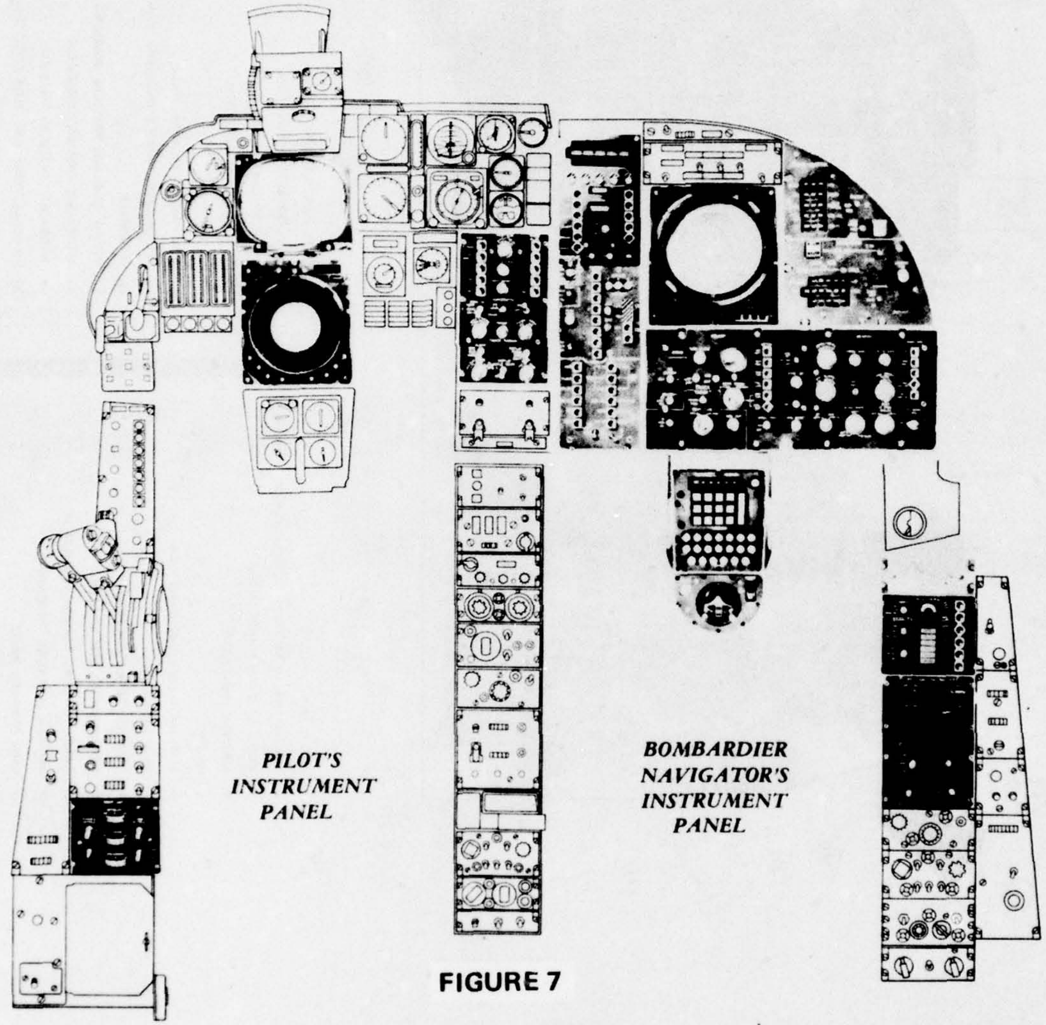


FIGURE 7

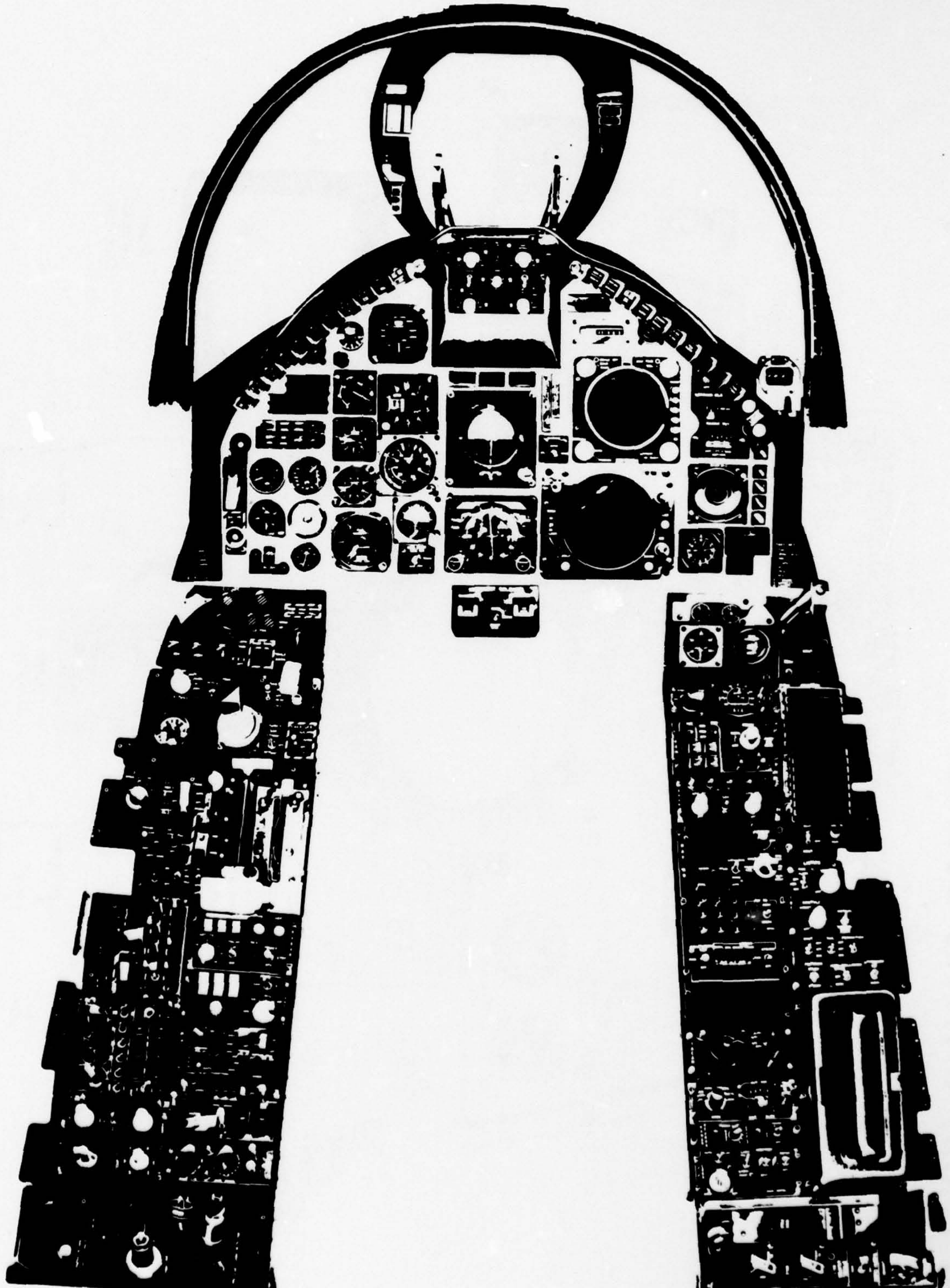


FIGURE 8

F-14 FLIGHT OFFICERS COCKPIT

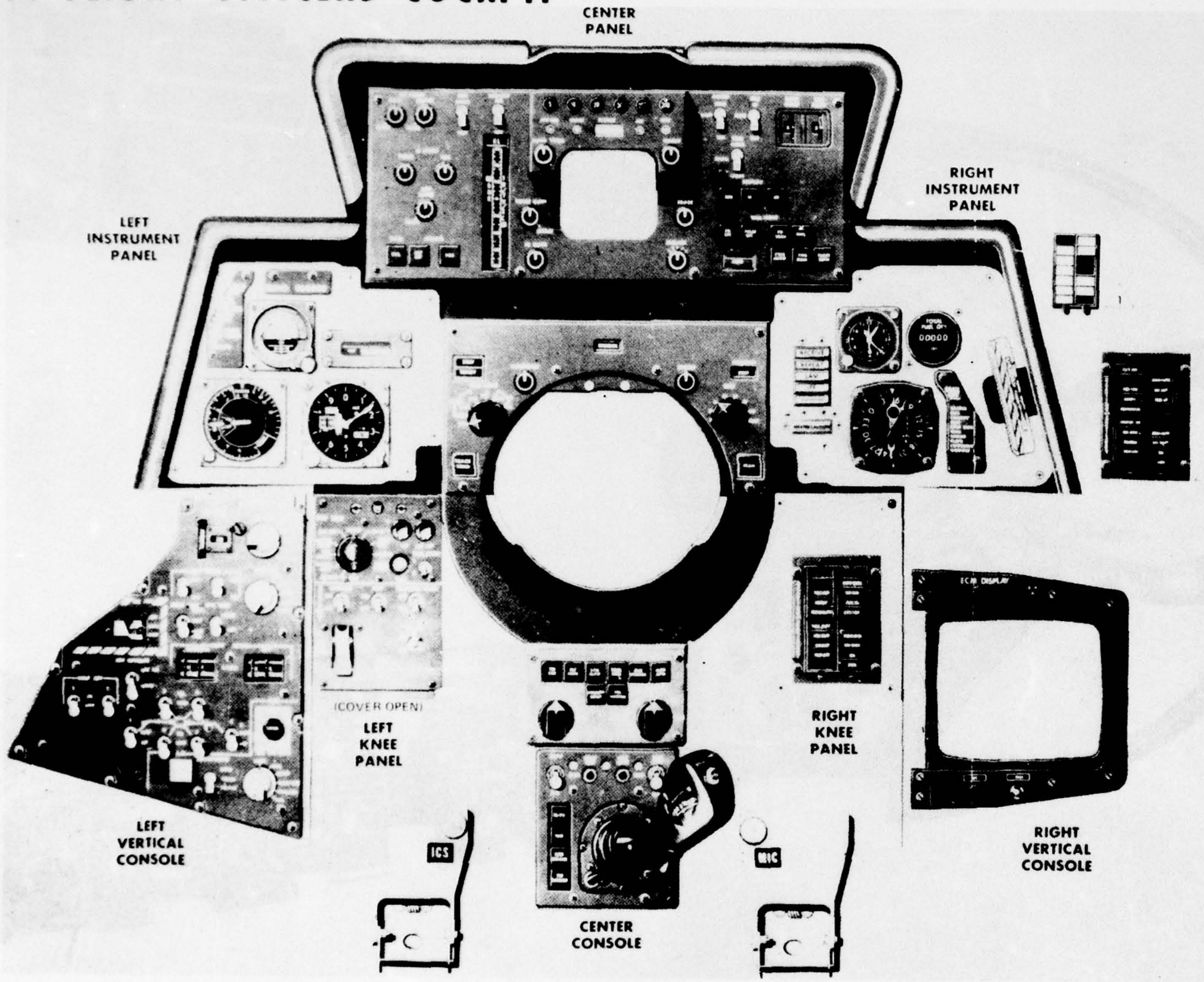


FIGURE 9

F-14 FLIGHT OFFICERS COCKPIT

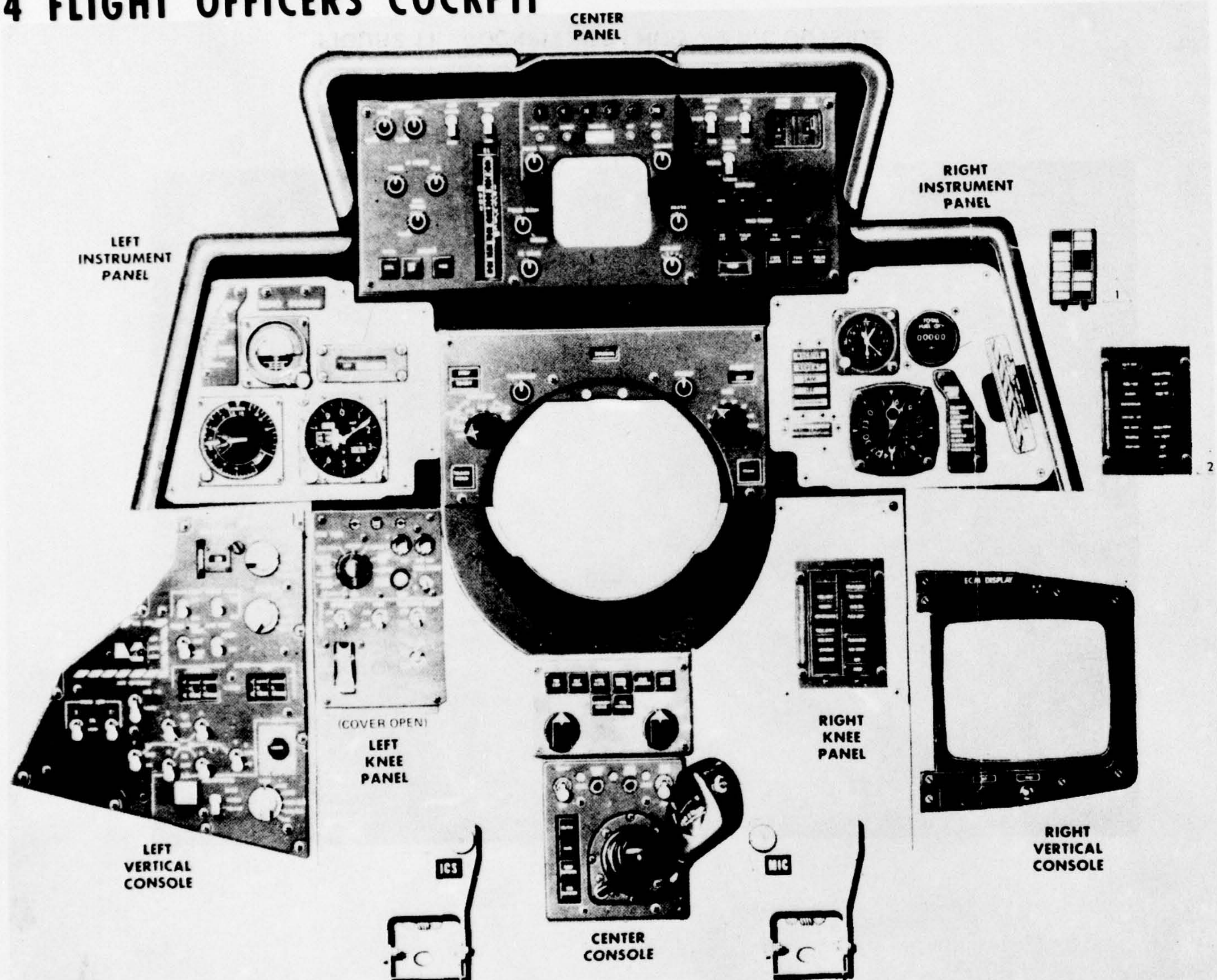


FIGURE 10

70

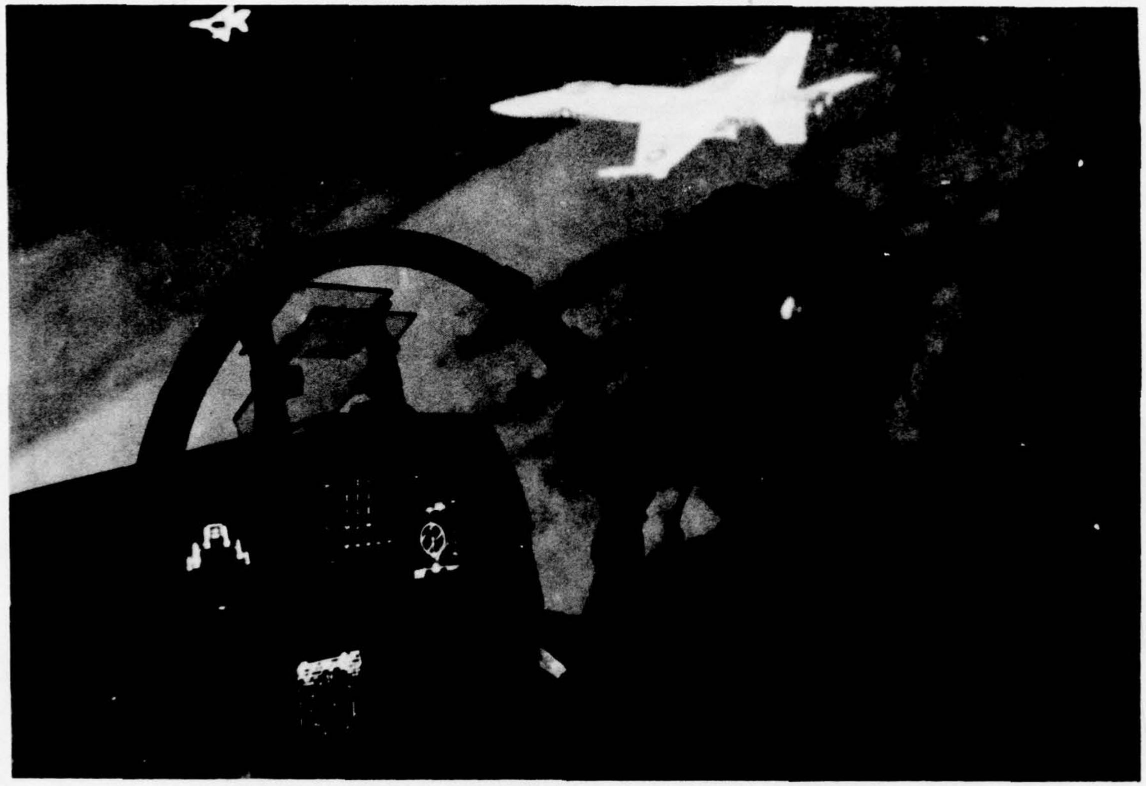


FIGURE 11. COCKPIT WITH HUD – 2 A/C OUTSIDE

Information Type Vs Application

Display technology encompasses a wide variety of distinct display devices implemented through a variety of display media and addressing techniques to satisfy a user's specific display application.

A Tri Service Working Group on Display Technology has bounded the problem by defining the types of information which can be presented to an operator.

There are three basic types of information in military aircraft. These basic classifications are: imaging or video, graphic, and message. (Figure 12). The order is important because each classification encompasses those that follow.

For the purpose of this discussion, the following definition of each type of information will be used:

a. Video Information (Figure 13)

Video information is characterized by today's raster television where high-data-rate (at least 30 times a second) information is presented in a pictorial form with multiple shades of grey. This includes sensor information such as Forward Looking Infrared (FLIR), low light level television (LLLTV), scan-converted radar and computer generated scenes such as a contact analog. Presently used resolutions of 525, 875, and 1024 lines are being considered as typical.

b. Graphic Information (Figure 14)

Graphic information presents information in both alphanumeric and simple line drawings with typically two levels of luminance in addition to the off state. These devices would be utilized for alphanumeric and graphic information from the aircraft, avionics, engine, and ordnance subsystems. Typical resolution requirements is several hundred lines for precise symbol positioning.

c. Message Information (Figure 15)

Messages are comprised of alphanumeric information at low-data rates with not more than two levels of luminance in addition to the off state. This would be used for caution or warning as well as for general command and control applications. Typical requirements indicate message formats of up to 20 characters by 15 rows in which each alphanumeric is arranged in a 5 x 7 or 7 x 9 dot matrix configuration.

The sample data list shown (Figure 16) portrays representative information of specific airborne applications for each of the three types of data. It is necessary to show where each of the information type shown will be utilized to design a particular display end product.

The end products shown (Figure 17) and described below are all cockpit mounted units. They are subject to the full military aircraft environment (MIL-E-5400) of ambient temperature, pressure, shock, vibration, acceleration, EMI, nuclear radiation, and humidity. They must also resist damage from abrasions, oils, fuels, grease, and hydraulic fluids and must be readable

INFORMATION TYPE

NADC

- VIDEO
- GRAPHIC
- MESSAGE

FIGURE 12. THREE CLASSIFICATIONS

VIDEO DEVICES

- RASTER TELEVISION
- HIGH DATA RATE
- MULTIPLE SHADES OF GRAY
- RESOLUTION OF 525, 875, AND 1024 LINES
- USED FOR FLIR, LLLTV, & SCAN CONVERTED RADAR

FIGURE 13. VIDEO DEVICES

GRAPHICS DEVICES

- ALPHANUMERIC AND SIMPLE LINE DRAWINGS
- 2 LEVEL LUMINANCE PLUS OFF
- RESOLUTION OF SEVERAL HUNDRED LINES
- USED FOR DISPLAY OF GRAPHIC DATA FROM AIRCRAFT, AVIONIC, ENGINE, AND ORDNANCE SUBSYSTEMS

FIGURE 14. GRAPHICS DEVICES

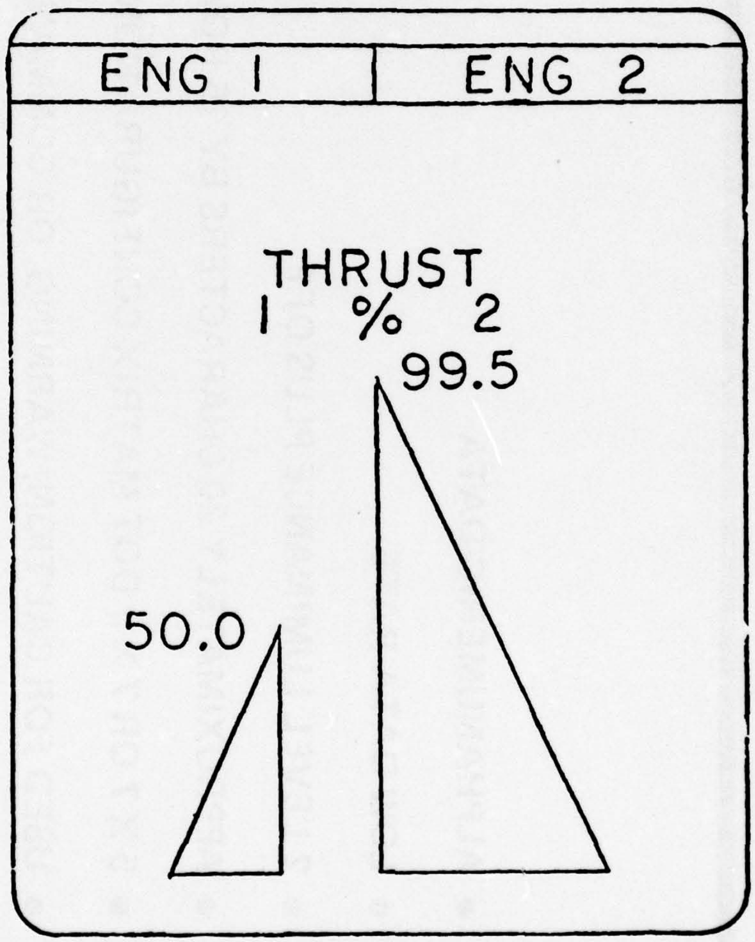


FIGURE 14A. GRAPHIC SAMPLE

MESSAGE DEVICES

- ALPHANUMERIC DATA
- LOW DATA RATE
- 2 LEVEL LUMINANCE PLUS OFF
- APPROXIMATELY 20 CHARACTERS BY 15 ROWS
- 5 X 7 OR 7 X 9 DOT MATRIX CONFIGURATION
- USED FOR CAUTION, WARNING, OR COMMAND/CONTROL

FIGURE 15. MESSAGE DEVICES

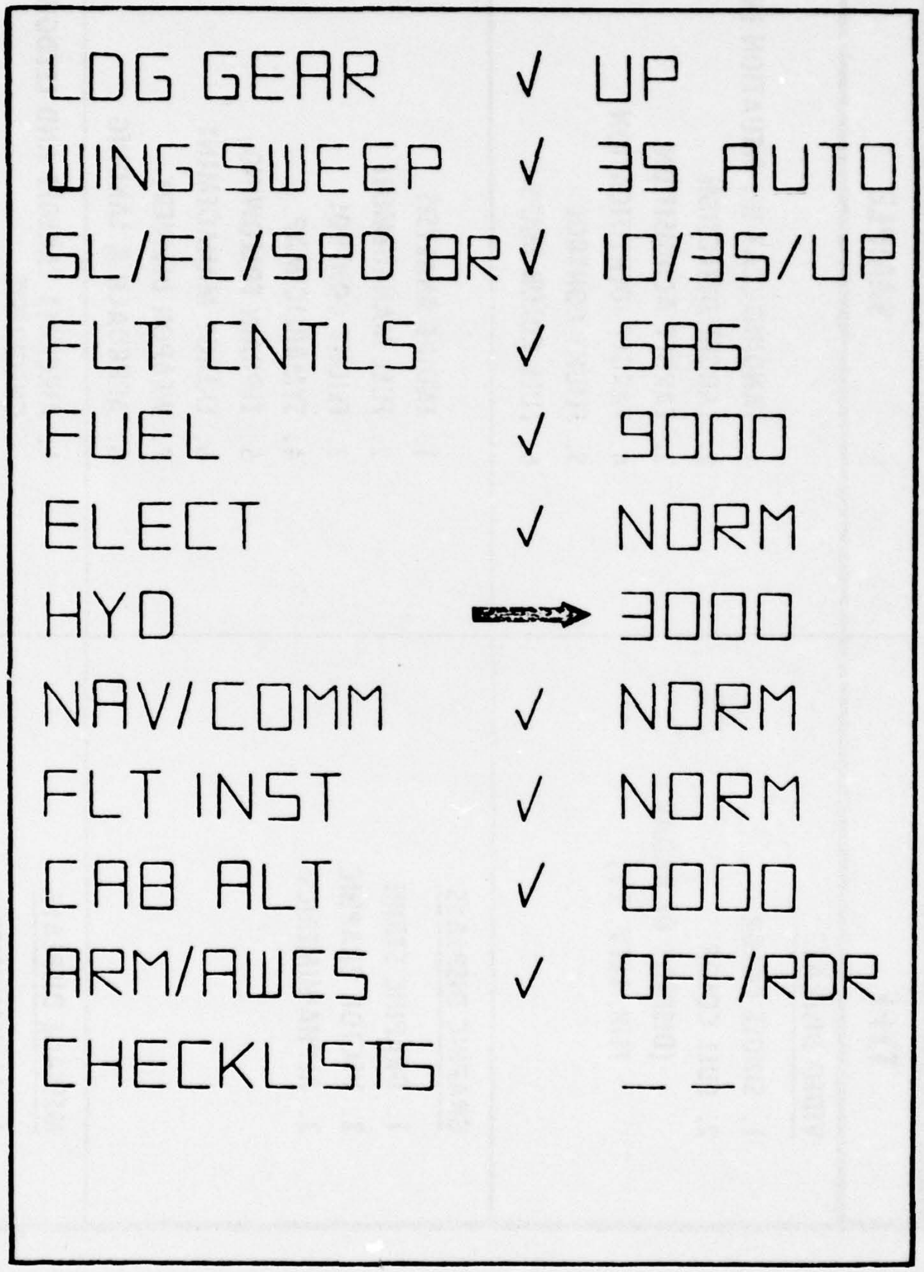


FIGURE 15A. MESSAGE SAMPLE

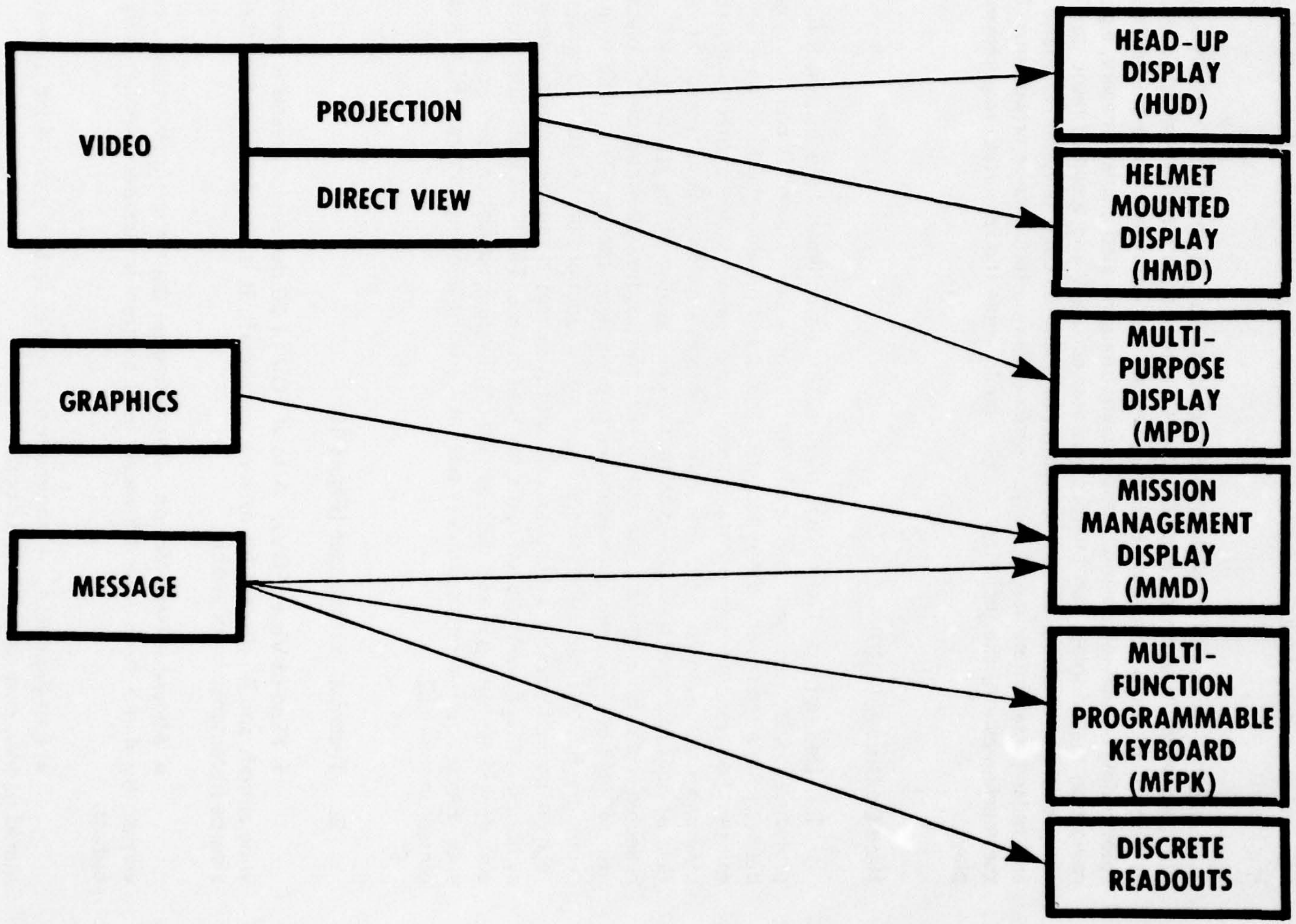
FIGURE 16

SAMPLE DATA LIST

TYPE	SAMPLE
<u>VIDEO DISPLAYS</u> 1. SINGLE COLOR 2. FULL COLOR (DISPLAY OF RADAR FLIR, LLTV, TV)	1. LANDING (CAT III) SITUATION INFORMATION 2. TARGET DETECTION 3. TARGET ACQUISITION 4. TARGET IDENTIFICATION 5. FLIGHT CONTROL 6. FULL COLOR MAPS
<u>GRAPHIC DISPLAYS</u> 1. GRAPHIC STRIPS 2. VECTOR GRAPHIC 3. ALPHANUMERICS	1. ENGINE ANALYSIS 2. FUEL MANAGEMENT 3. FLIGHT CONTROL 4. SYMBOLIC MAP 5. TERRAIN FOLLOWING 6. ENERGY MANAGEMENT 7. WEAPON DELIVERY 8. APPROACH & LANDING
<u>MESSAGE DISPLAYS</u> 1. ALPHANUMERIC	1. AIRCRAFT TAKEOFF AND LETDOWN CHECKLISTS 2. NAVIGATION READOUTS 3. ENGINE INSTRUMENT 4. FLIGHT CONTROL DATA 5. WEAPON STATUS 6. ENERGY MANAGEMENT

FIGURE 17

RELATIONSHIP BETWEEN THE INFORMATION TYPES AND THEIR POSSIBLE UTILIZATION AS USABLE END PRODUCTS



in ambient light conditions ranging from moonless night to bright daylight. The readability requirements imposes further demands on the display in regard to such features as luminance, contrast ratio and resolution while at the same time reflections off the canopy must be at a minimum.

Another feature of possible interest is color. Adding color to any of these products definitely enhances its aesthetic appeal; however, attempts to establish performance improvements as a result of using color have been few and far less definitive. Some studies have shown that color-coding of high-information density computer generated display imagery, e.g., an electronic navigation map display, can improve operator accuracy and speed of response. To date, however, rendition of sensor-video information in both true color television and false color infrared and radar presentation has shown less pronounced performance improvements. Depending on the mechanization, the inclusion of color could triple the resolution requirements on the display.

Head-Up Display (HUD)

1. **Description.** The (HUD) (Figure 18) is a collimated (focused at infinity), optically projected display designed specifically for airborne use. The HUD combining glass is located between the aircraft windscreen and glare shield and provides the function of an optical beam-splitter. The combiner/beamsplitter transmits the real-world scene directly and reflects the display image so that the two (2) superimposed images are viewed simultaneously by the pilot. The field-of-view of the HUD is scaled to be the same as that of the real-world scene. Because the reflected image is collimated, the angular size and position of symbol cues projected within the display field-of-view remain constant with pilot head motion. The HUD is used to project vector-graphic or video information. The primary functions of the HUD are weapon aiming and flight control, therefore a high quality optical system is required that can maintain accurate symbol positioning over the entire display field-of-view. The HUD is also used to display symbol cues for other mission modes such as take-off, landing, navigation, and terrain following/avoidance. Electro-optical sensor displays such as Forward Looking Infrared (FLIR) can also be presented on the HUD.

2. **Technical Performance (Figure 19)**

- **Field-of-View (FOV).** A total FOV of 20 degrees or greater is desirable for fixed-wing aircraft and 40 degrees for rotary-wing aircraft. It is also desirable that the total field-of-view be instantaneously viewable.

- **Allowable Head Motion.** Depending on the aircraft installation, a nominal 3-inch vertical by 4-inch horizontal allowable head motion is required (applies only to refractive optics).

- **Exit Pupil Size.** A minimum of 3-inches vertically and 4-inches horizontally is required (applies only to reflective optics).

- **Contrast Ratio.** Nominally, 1.2 against a 10,000 fc background is required (for graphics).

CONVENTIONAL CRT HUD SYSTEM

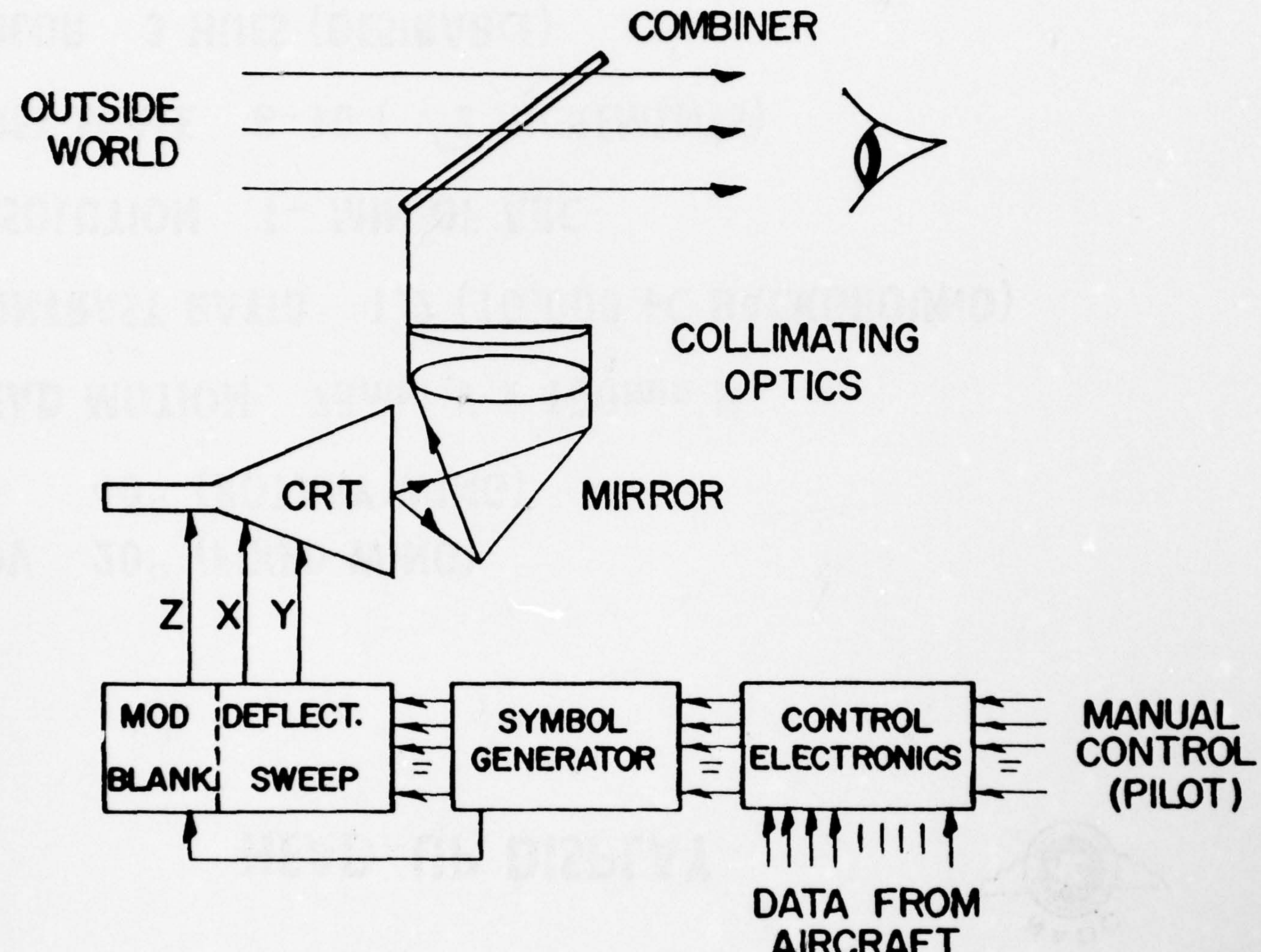


FIGURE 18

NADC

HEAD-UP DISPLAY

FOV 20° (FIXED WING)
40° (ROTARY WING)

HEAD MOTION 75mm V x 100mm H

CONTRAST RATIO 1.2 (10,000 FC BACKGROUND)

RESOLUTION 1- MIN OF ARC

GREY SCALE 8-10 ($\sqrt{2}$ INCREMENTS)

COLOR 3 HUES (DESIRABLE)

FIGURE 19

• **Symbol Position Accuracy.** One milliradian over the central 5 degrees of the field-of-view. Less than 5 milliradians over the total field-of-view.

• **Display Resolution.** One to three minutes of arc per picture element (pixel) is required throughout the total FOV. (This corresponds to as many as 2400 picture elements needed for a 40-degree (FOV).

• **Grey Scale.** This is needed only when raster video is displayed. Eight to ten luminance increments ($\sqrt{2}$) are involved.

• **Color.** Three or more hues are desirable depending on application.

3. **Packaging.** The combiner is located between the aircraft windscreen and glare shield with sufficient clearance to minimize secondary reflections from the windscreen. The HUD must clear the pilot eject line, usually with a gunsight camera mounted in front of the combiner. The HUD can extend beyond the surface of the instrument panel, but it must not obscure the pilot's line-of-sight (LOS) to other surrounding displays and controls or the pilot's "over-the-nose" LOS. These geometric constraints determine the specific optical performance that can be obtained in any particular aircraft installation.

Helmet-Mounted Display (HMD)

1. **Description.** The HMD is a collimated (focused at infinity), virtual image type display that is usually mounted to, or built integrally with, the pilot's flight helmet. The image is generated on a miniature image source (miniature solid state array or cathode-ray tube) with a display size of typically one inch. The image is relayed from the miniature image source, through an optical system to a point where it is projected onto a final beam-splitter, or the helmet visor, and into the pilot's eye. Figure 20 shows a stereoscopic version with the display off the helmet and the image is transmitted via a fiber optics bundle. The pilot sees a virtual image of the displayed information, superimposed over his view of the real-world. Because the display system is coupled to the head, the pilot has the capability for the system's wide field-of-view display presentation, no matter what his head line-of-sight might be, and therefore is not constrained to a head-down position to obtain the required display information. The typical, instantaneous field-of-view of the HMD would be equivalent to having a large screen (21-inch) television display in the cockpit. The HMD is used to present a variety of different types of information. A primary use is the presentation of high resolution video imagery from the various, FLIR, daytime, and low-light-level TV sensors on board the aircraft. This type of information is used for vehicle pilotage, target acquisition, weapon delivery, navigation, and terrain avoidance aspects of the mission. The HMD is also used for the presentation of a variety of different types of symbology. These range in complexity from simple gunsight reticles and discrete cues to flight control and navigation symbology typical of headup display presentation, complex stabilized weapon delivery symbology, and vector-graphics. In short, the type of information being presented by the HMD system covers the full gamut of information presented by any of the other cockpit displays.

2. **Technical Performance.** (Figure 21). The characteristics of the HMD system have varied over the years of its evolution based on the technologies being applied to its implementation and the projected application requirements. Current HMD systems could be described from

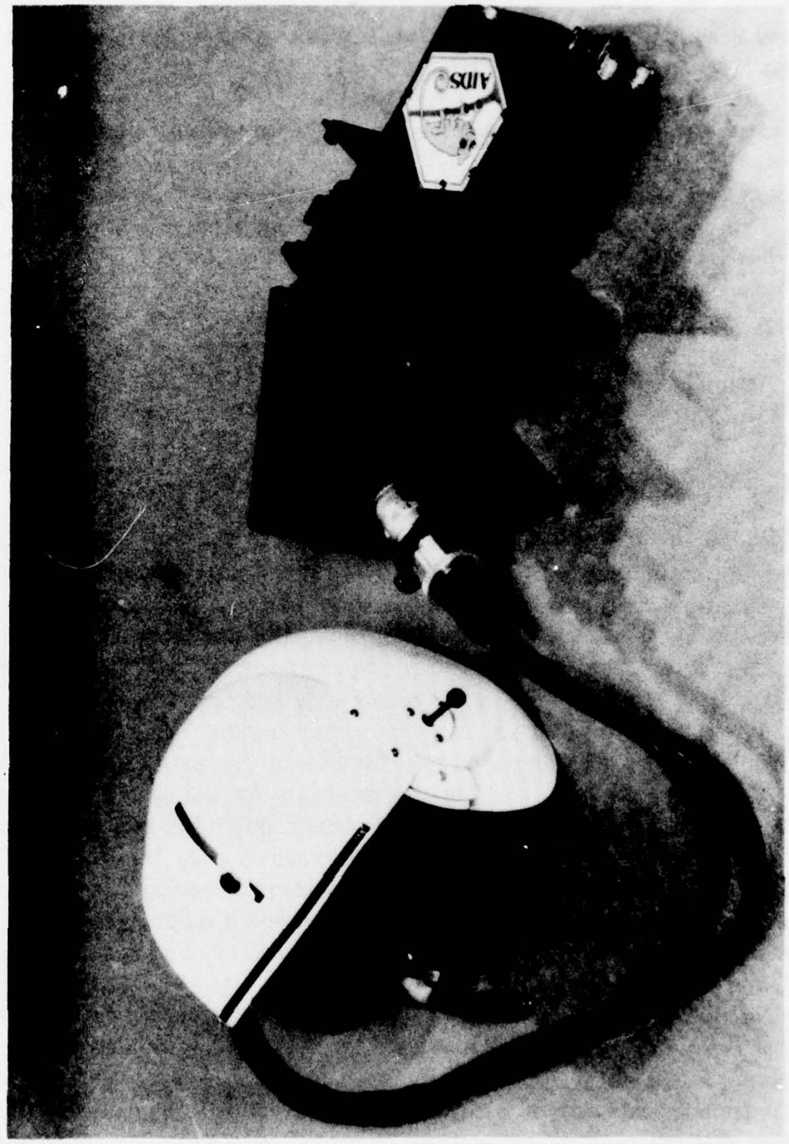


FIGURE 20. HMD HELMET HOOKED UP TO AIDS BOX

HELMET MOUNTED DISPLAY

FOV 30° X 40°

EXIT PUPIL 12mm VX 15mm H

BRIGHTNESS 1–10 FL (NIGHT)
300–400 FL (DAY)

GREY SCALE 8–10 ($\sqrt{2}$ INCREMENTS) MINIMUM
10–16 DESIRABLE

SENSOR COMPATIBILITY 525 & 875 LINES

COLOR 3 HUES (DESIRABLE)

FIGURE 21

the quite similar requirements for the system posed by its application in the Army's Advanced Attack Helicopter, Navy V/STOL applications, and the Air Force Single Seat Attack efforts. Typical FOV requirements for the HMD are 30 degrees vertical by 40 degrees horizontal. The exit pupil, which is the amount of translation either vertically or horizontally allowable for the eye relative to the system on the helmet, while maintaining the full FOV, is usually 12-15 mm or greater. Since these systems are planned for day/night mission scenarios, typical peak luminance levels of 1 to 10 fl for night and 300 to 400 fl for day operation are dictated. Any discussion of luminance and contrast requirements for the HMD should keep in mind that the image displayed is a virtual image and this "see-through" scene is usually viewed against a variety of ambient backgrounds. The resolution of the miniature (1-inch) image source for the HMD should be compatible with current 525 and 875 line sensors. Display refresh rate should be at least 30 times/second and the accuracy and update rate of the HMD system should be compatible with the presentation of flight control and weapon delivery information in several of its modes of operation. Currently, HMD systems are single color devices. Multi-color and full color capability is desirable.

3. **Packaging.** The components of the system mounted on the helmet, including the miniature image source, optics, and final combiner or visor, are subject to additional design requirements by virtue of the fact that they are an integral part of the flight helmet. A typical weight limit for the complete helmet/HMD system including electronics is 3.5 pounds. Of equal importance is the placement of the additional components on the helmet in a manner that minimizes a change in the resultant center-of-gravity of the overall helmet system. Minimum size as well as weight is important to allow the pilot complete freedom of head movement within the cockpit. Because the user is linked via cable to an electronics unit on the airframe, an appropriate means of quick disconnect must be provided for ejection or rapid ground egress. Typical power requirements for current HMD systems are in the order of 100 watts. A power reduction by an order of magnitude is desirable.

Multi-Purpose Display (MPD)

1. **Description.** The MPD is a direct view, flexible information format display having the capability to display both graphic and video information. It provides the aircrew with the ability to both monitor and exercise real-time control over the aircraft in relation to its outside environment. The MPD may also serve in a failure backup mode as a display for information generally found elsewhere in the cockpit. Depending on the control-display requirements assigned to a multi-purpose display, it may either be capable of performing all of the primary flight display functions in the cockpit or, alternatively, just a portion of them. The Horizontal Situation Display (HSD) and the Vertical Situation Display (VSD) are two classes of MPD that are associated with two specific types of flight control display information.

The HSD is a flexible information format (i.e., multifunction) display that, at a minimum, displays the heading information portrayed on a conventional electromechanical Horizontal Situation Indicator (HSI) or a Radio Magnetic Indicator (RMI). In essence, it is an MPD that has a designated information function, that being the display of information giving aircraft orientation and any related situation information with respect to a position in a plane horizontal to the earth's surface. In addition to the heading indication, bearing pointers, distance, and course deviation indications provided by an HSI, the HSD should be able to provide combinations of:

Aeronautical charts and/or Electronically Generated Maps
Navigation, Target/Drop Zone Identification
Electro-Optical and Radar Sensor Video
Flight Control Cues
Electronic Warfare Information

The VSD is a flexible information format (i.e., multifunction) display which, as a minimum, display the attitude information portrayed on an electromechanical Attitude Director Indicator (ADI). The VSD is also a form of MPD that has a designated function it must perform, that being the display of the following kinds of information:

Electro-Optical and Radar Sensor Video
Target Acquisition and Identification Sensors
Weapons Delivery
Caution, Warning, and Advisory Annunciation

2. **Technical Performance.** (Figure 22) The sensor-video imagery of target detection and identification tasks associated with search and rescue, reconnaissance, and weapon delivery are the controlling factors that determine the resolution requirements for the MPD. Under ideal conditions, the limit of human visual capability indicates that the ultimate HSD and VSD needed to perform these tasks should be about 12 inches square and have a picture element density of 307 elements/inch in both the X and Y direction (13 million image elements) for a 28-inch viewing distance. This corresponds to 2.5 pixels/arc minute of subtended angle and is based on a 0.4 minute of arc minimum separable visual acuity limit for a pilot with 20/20 vision. A 12 inch by 12 inch display of 13 million image elements represents a total linear picture element (pixel) count almost ten times greater than current systems.

The requirement for both the number of grey shades and the luminance ratio between adjacent shades on a video display are the subjects of considerable controversy. The reported number of grey shades needed as a minimum to fully satisfy viewer visual requirements varies from five to thirty for fixed daylight viewing conditions, with luminance ratio requirements varying from $\sqrt{2}$ to 2. Experimental studies would be required to determine if a grey scale range greater than 17:1 (obtainable by photographic media and incremented in seven equal 1.5 luminance multiple steps) would provide improved target detection and identification capability. If proven, this number would be an ideal preliminary minimum requirements.

Sensor-video information used to provide situation information other than the previously described can be satisfactorily displayed with between 60 and 120 pixels/inch on a 500-line display. Minimum requirements for vector-graphics portrayed on an MPD is also 60 pixels/inch, with the additional requirement that the pixels be highly defined. In the event it is desired that small display characters rotate, then a resolution closer to the 120 pixels/inch limit (independent of display size) is needed to maintain high levels of visual performance.

3. **Packaging.** Depending on the functions to be displayed in a particular aircraft in support of satisfying its mission requirements, multi-purpose display sizes varying from a minimum of 4 x 4 inches up to 12 x 12 inches (and possibly larger) can be envisioned. Maximum utilization of panel space makes it desirable to maximize the ratio of display active area to the total panel area occupied, subject to the constraints imposed by the need for light sensors, controls, and switches. Conversely, minimum separations between functionally different types

MULTIPURPOSE DISPLAY

SIZE FROM 4" X 4" TO 12" X 12"

RESOLUTION 60–120 PIXELS/INCH

GREY SCALE 5–30 ($\sqrt{2}$ INCREMENTS)
17 NOMINAL

COLOR 16 HUES

FIGURE 22

of display information and the need for instrument panel structural integrity both suggest limiting the proximity of adjacent displays. Nominally, 10% of the active area linear dimension of the larger of two viewed displays is needed to separate different but related task information. Larger distances are needed to separate information for unrelated tasks.

Mission Management Display (MMD)

1. **Description.** The MMD is a flexible information format display that has as its primary function the portrayal and interactive control of high information content computer generated information. The MMD portrays aircraft related subsystems data such as engine, fuel, hydraulic, oxygen, and life support systems informations; ordnance data such as weapon type, status, and readiness; and avionic subsystem modes and status such as navigation, communication, electronic support measures and countermeasures, sensors, and processing. Each type of information is prioritized for each mission mode so that the most important data at the particular moment of the mission receives the highest attention.

2. **Technical Performance.** (Figure 23) An MMD is a graphic display that has no requirements for video presentations. The MMDs presently being used are monochrome CRTs utilizing two discrete brightness levels in addition to off. Current sizes are approximately 5 inches x 7 inches, oriented as a normal page of a book. The 5 inch x 7 inch size is a compromise between the 9 inch x 12 inch requested by human factors studies and the 4 inch x 5 inch limitation based on airframe installation requirements. Present studies utilizing CRTs indicate that an alphanumeric character must be at least 0.187 inches high, with an ideal height being 0.25 inches (assuming a 28-inch viewing distance). The minimum number of character lines is 14, each having the minimum capacity of 22 characters/line. The graphics capability should include simple graphs, geometric shapes and lines generated by a display with uniformly spaced horizontal and vertical picture elements. Color is desirable for both of these applications to accentuate information.

3. **Packaging.** The MMD is more likely to be positioned to one side than to be centrally located with respect to the pilot, as in the case of the VSD and HSD. This can present an unusual depth requirement because of the fairing-in of the structure and skin towards the nose of the aircraft. This depth limitation presents unique possibilities for flat panel displays. Even more stringent in physical size is the high acceleration cockpit. In the high acceleration cockpit, the pilot's knees are brought upward and the whole body is rotated around the head so as to increase the pilot's ability to withstand higher g's without blacking out. The position of the knees in this configuration is where the MMDs would normally be. An apparent solution is to construct them in such a manner that they can be swung out of the way to make room for the knees. The type of information presented on the MMD is not required during this short-duration, high-stress portion of the mission since the pilot's complete attention is on the HUD or HMD. In order to move the display, the depth dimension is very important. The CRT, for instance, with its long neck would not be capable of being moved. Therefore, the development of the flat panel display may be critical to the cockpit of these kinds of aircraft.

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MISSION MANAGEMENT DISPLAY

SIZE	FROM 5" X 7" TO 9" X 12"
ALPHANUMERICS	.187" MINIMUM .25" IDEAL
CHARACTER LINES	14 MINIMUM
CHARACTERS/LINE	22 MINIMUM
COLOR	3 HUES

FIGURE 23

Multi-Function Programmable Keyboard (MFPK)

1. **Description.** (Figure 24) The MFPK will integrate the control of several sets of functions presently provided by separate/dedicated control panels and the management of several primary multifunction displays. It will reduce operator real-time workload both by allowing preselection of flight tasks on a functional or mission-segment basis and by providing flexible but orderly procedures in the conduct of the total crew station management. Through the incorporation of programmable switches and information processing, the plethora of dedicated control switches can be sharply reduced and I/O cueing, heretofore not available, can be provided. A variety of control display formats will be provided both by the MFPK and/or an MMD with touch panel capability.

2. **Technical Performance.** (Figure 25)

- Legends per switch - Two rows of four to eight characters per row.
- Matrix per individual legend - Seven by nine preferred, five by seven minimum
- Number of switches - Fifteen to thirty
- Contrast and Viewability - Under bright sunlight at a contrast ratio of 1.2 and usable with night-vision aided devices (goggles)

3. **Packaging.** For maximum Tri-Service utilization, the MFPK should be designed to fit the standard 5 3/4 inch console mounting as described in MIL-P-7788.

Message and Discrete Readouts

1. **Description.** Discrete readouts take the form of individual or grouped numerics and alphanumerics. They are used in applications which range from one or two digit displays and legend lamps, to message displays of several rows of up to 20 or more characters per row. Modular readout devices, specifically numerics, alphanumerics and barographs, are needed to provide legible, reliable, variable-format control display components. Readouts will be needed both in discrete and mosaic formats (to allow variable fonts and positioning in alphanumeric modes and/or line positioning for barograph applications).

It is imperative that these devices be developed as modules employing three basic constructs:

- Segmented numerics
- Dot matrix alphanumerics
- Small area mosaics

These modules are required to be abuttable on all four sides and incorporate all necessary drive/address circuitry. This concept will allow a wide variety of form factors and display areas

INTEGRATED CONTROL PANEL

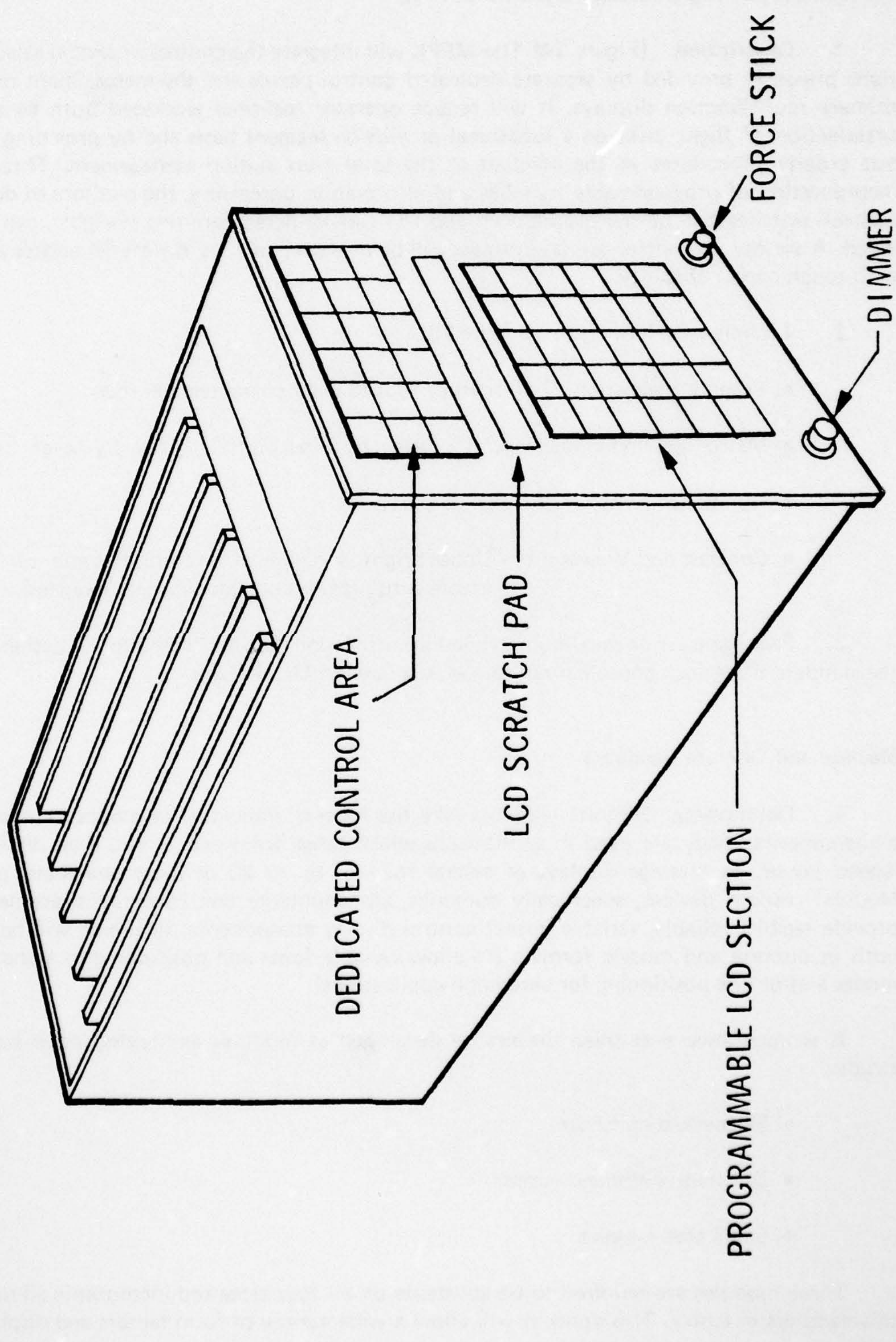

FIGURE 24

MULTI-FUNCTION PROGRAMMABLE KEYBOARD

LEGENDS PER SWITCH	2 ROWS 4-8 CHARACTERS PER ROW
MATRIX ARRANGEMENT	5 X 7 MINIMUM 7 X 9 PREFERRED
SWITCHES QUANTITY (IN MIL-P-7788 REQ'T OF 5¾" CONSOLE)	15 - 30
CONTRAST/VIEWABILITY	1.2 (BRIGHT SUNLIGHT - NIGHT GOGGLES)

FIGURE 25

which are appropriate for application of these devices. Applications include: control panel numeric and alphanumeric readouts; flight, mode, and caution legend lamps; and multi-legend display switches.

2. Technical Performance. (Figure 26)

Readability	10^4 fc to 10^{-4} fc (with night vision goggles)
Contrast ratio	1.2 at 10^4 fc
Resolution	30 to 150 pixels/inch
Character fonts	5 x 7 to 10 x 14

3. Packaging. The key packaging feature requirement is that of modular construction to allow use as a single display or in combination for use as a multi-numeric/alphanumeric message and barograph display.

Questions. (Figure 27)

Specific questions still needing answered are:

1. Do we understand the mechanisms of the eye/brain combination well enough to specify color requirements for an airborne operator?

2. Do we understand the Tradeoffs of Binocular vs Bi-ocular vs Monocular for airborne operators well enough to specify requirements?

3. Should automatic compensation be incorporated in both head-up and head-down displays to allow for adjustments due to changes from high ambient (outside the cockpit) to low ambient (inside the cockpit) and vice-versa as a function of time?

NADC

MESSAGE & DISCRETE READOUTS

READABILITY 10^4 fe – 10^{-4} fe (GOGGLES)

CONTRAST RATIO 1.2 AT 10^4 FC

RESOLUTION 30 – 150 PIXELS/INCH

CHARACTER FONTS 5 X 7 MINIMUM
10 X 14 DESIRED

FIGURE 26

AD-A080 958 NAVAL AIR DEVELOPMENT CENTER WARMINSTER PA AIRCRAFT --ETC F/G 6/16
RESEARCH NEEDS RELATING TO AIRCREW VISUAL REQUIREMENTS: PROCEED--ETC(U)
APR 79 H ROSENWASSER, G T CHISUM, P E MORWAY

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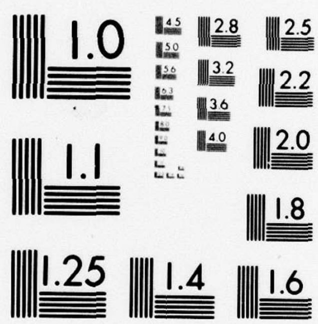

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

QUESTIONS

1. COLOR
2. BINOCULAR - BIOCULAR - MONOCULAR
3. AUTOMATIC BRIGHTNESS COMPENSATION

FIGURE 27

WILLIAM G. MULLEY

DISCUSSION

COL TREDICI: I think in the Head-Up Display you had something about resolution being one minute of arc. That means 20/20 visual acuity. So, everybody would have to have that or better.

MR. MULLEY: Unfortunately, we have to design for 20/20.

CAPT GINSBURG: At the Visual Systems Display Branch, we in vision research are very sensitive to the type of specifications that you are putting up. I would like to follow Colonel Tredici's question and ask: Where is this one-minute resolution coming from: Why do you specify what you begin with?

MR. MULLEY: I think it's from the visual acuity. That's the minimal discernable that the eye can see. It's sort of a standard for 20/20.

CAPT GINSBURG: What I would suggest you want to do is to tailor your resolutions to a particular task at hand rather than drive technology to the limits like we have in the displays.

In the Air Force we have something like 2,000 displays that some manager has to choose from for a cockpit, and clearly a lot of those displays are overkill in the number of lines per resolution. Those measures don't really relate to task performance. For example, you don't need a 2,000 line display for any sensor system we have developed today. If you put it at a certain distance the visual system isn't going to see higher than 60 cycles per degree optimally. The point is, you really can't talk about the number of lines in a display. What you have to relate it to is the resolution of the sensor information coming in to make some sense. In some displays you might only need 500 lines. In others you might need 200 lines.

MR. MULLEY: That's right.

CAPT GINSBURG: But when you start specifying one minute resolution for a display that's going to change its distance, you are going to drive technology up to these 2,000-line displays which may be completely irrelevant.

MR. MULLEY: If we go to the flat panel, which hopefully we will be able to do in the modular sense, then we will be able to use the same technology and modulars for 500-line displays and 875, 1,000, or even 2,000 if somebody needs it. It is not a whole new development. It will be a module. The resolution may depend on the field of view. If you go to a larger field of view and can't get this sensor information, you may want to go to a 2,000 line because it's spread out this much.

DR. WOLBARSHT: There are some simple guidelines that you can understand in at least some of the questions you ask. In the first place, the relation between color and acuity, I think the confusion in that field is due to the fact that when you introduce color, you usually degrade the resolution, so that you don't really present equivalent types of displays. For example, in color television, the overall resolution is much lower than it is in the black and white presentation.

MR. MULLEY: Right.

DR. WOLBARSHT: So that you are comparing in one sense apples and oranges. They aren't the same kind of displays anymore, although you can get the same things out of them from color as what you used to get out from the resolution.

Now, the other question is: When you are presenting monocular and binocular displays, you should remember that when you only present something to one eye, the other eye is a glare source and you degrade the overall contrast of the system. So that you have to take that into account immediately. You can't get away from it. The real advantage of the binocular display is not that you have any stereopsis, because I don't think that plays a role after about 20 feet, but that you have a higher resolution in the system due to improved contrast.

MR. MULLEY: There are techniques where you don't lose resolution such as color penetration. That has extremely high resolution, the same as monochrome- -

DR. WOLBARSHT: That's true. But most of the work up to now hasn't done that. That's why it's difficult to understand what the value is, because the experiments weren't done in the way to bring out the exact answer.

MR. MULLEY: Hopefully, technology will keep advancing.

DR. COHEN: I would like to pick up a third question about the possibility of increasing intensity of your display when the pilot looks out of the cockpit and then looks back in. To do this you probably want some way of monitoring the efficiency of the visual system as it changes from different states of light and dark adaptation. A possible technique, and one that was suggested recently at a meeting of the Airline Pilots Association, was the use of the evoked cortical response or possibly even an ERG as an indicator of the pilot's visual system's sensitivity, and then process that information into the devices that will control the intensity of the visual displays and there by have constant subjective brightness achieved or an approximation thereof.

MR. MULLEY: Are you talking about sensors on the individual that detect these things and then feed back?

DR. COHEN: Yes, because what you are looking for is constant subjective brightness so that the man can still resolve the visual displays. And to find out what that is, you have to monitor the integrity of his visual system.

MR. MULLEY: That would vary from individual to individual. Are you saying that you can't store that kind of a chart for a 95th percentile man?

DR. COHEN: Either that or you have to specify what the intensity of the ambient light was outside of the cockpit. So you have to process that information. It might be simpler to directly process the information regarding the integrity of the visual system and subjective intensity as it relates to that information, and something like the evoked cortical response might be a useful tool.

DR. LIT: I wonder what the data are for your assumption that identical evoked potentials imply identical brightness responses on the same subject.

DR. COHEN: I am not saying identical, but as you change the intensity of a light source, the evoked responses of an individual will decrease as intensity decreases. So, if you can get some sort of a calibration for that person, you might be able to maintain subjective brightness.

DR. LIT: Well, actually, I think it's more measurable in terms of latency effects. But I suppose you could measure latency as well as amplitude. I am not really an expert in this area, but I certainly would like to see evidence that would show that once you get the same output, you necessarily have the same perception. And I'm not at all sure that that's true. There could be compensations in which things could be brighter even though the evoked potential hasn't changed. That's what might make your suggested method a bit hazardous.

DR. GINSBURG: One of the problems we have in the Air Force is the fact that you are going from one display to another. They do have different brightnesses. And it may be nice to have the brightnesses of the two displays about equal, and one suggestion has been that you can use the evoked potential, but if you look into these techniques or talk to people, you will find it is extremely difficult. It will take about two or three years of research to try and get this done in the laboratory. Now, if you want to translate this in the operational environment, you are talking about a few more years.

The basic question is: Are there no other ways to match the luminance of the displays without going to the point of putting electrodes on the pilot and having another complex box in the cockpit?

DR. NELSON: I am sure we all agree with Dr. Ginsburg that we should let the task and not the technology dictate the acuity of the display. I would mention parenthetically though that there is one sort of display where we do need high acuity, and that is if we intend to present stereoscopic depth information. There we face a visual system acuity measured not in minutes of arc but in seconds of arc.

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VISUAL AND CLINICAL CONSIDERATIONS

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USAF School of Aerospace Medicine
Aerospace Medical Division (AFSC)
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INTRODUCTION

This discussion concerns the visual and clinical research needs as they relate to the man, his machine, and the environment in which he performs. We will consider vision and the visual apparatus of the flyer in the areas of selection, maintenance, enhancement, and protection. In considering the machine, we will look at the needs for better and safer windscreens. In the environmental area, the old problems of hypoxia and dysbarism on vision are still with us, and the effects of much higher G-forces on the pilot will make it mandatory that we look at these effects, not only on his peripheral but his central vision as well. And, finally, in the environmental sphere, a totally new hazard has to be considered because it will affect almost anything that we have discussed to this point- -this is the effect of toxic gases (chemical warfare) on the aviator and his visual apparatus.

MAN

After 75 years that man has been flying we still have not thoroughly identified and prioritized the visual parameters which are important in flying. Prospective research in this area has been quite slim. The visual standards by which the military aviator has been selected have been largely empirical- -usually consisting of the judgment of "experts" or committees. Data is now being accumulated retrospectively by longitudinal clinical follow-ups, such as have been carried out at the USAF School of Aerospace Medicine (USAFSAM) for the last two decades. This should allow us to make better scientific judgments in this area.

Originally, the World War I visual standards were set up to select individuals with physiologic ocular perfection. This was so restrictive that a liberalization of the standards had to be made. Liberalization of the visual standards has been the method of operation ever since World War II. In fact, erosion in several areas considered vital has prompted the USAF Surgeon General (SGO) to call an Air Force-wide meeting to discuss pilot selection and physical standards for the 1980's and beyond. A good part of the discussion encompassed the visual standards for flying. Such a meeting was helpful since there was input from the operations sector as well as the medical. Nevertheless, still needed will be the necessity to identify and prioritize the visual factors that go into such a complex task as flying, with the projected outcome of being better able to select individuals who have the needed visual capabilities for the type of flying or aircraft that he will be operating. A most recent example being looked at is contrast sensitivity, such as is being done at the USAF Aeromedical Research Laboratory (AMRL) and furthermore,

there is a need to look at stereoscopic and dynamic visual acuity and their relationship to flying. This might then simultaneously expand our manpower pool and yet produce a more effective flyer.

MAINTENANCE

After the proper selection there is a need to maintain the flyer in the cockpit for a full career. The present cost of a fully trained jet pilot in the USAF is $600,000. The US Navy figures show $800,000 in training cost per pilot. Fortunately, the selection process has weeded out many of the ocular conditions which would shorten or terminate a flyer's career. However, there are still a number of ocular and visual conditions that do occur that can significantly affect a pilot's performance. We have studied the causes for referral to the Ophthalmology Branch, USAFSAM, and the number of cases and percentages are shown in Table 1, below.

TABLE 1

	Cases	Percentage
Glaucoma	182	23%
Retina	146	18%
Cornea	91	11%
Strabismus	80	10%
Neurological	59	7%
Migraine	51	6%
Cataracts	51	6%
Psychological	25	3%
Miscellaneous	110	14%

Glaucoma, as seen from the list, is the largest cause for referral to our department. However, our research and ensuing policies that were developed in the department have allowed us to salvage about 95% of these individuals so that most of them have returned to the cockpit with very little loss of efficiency. Approximately half of the next largest category, the retinal disorders, were central serous retinopathy. For occupations other than the aviator's, this condition would probably not be disabling. However, the aviator must be grounded in almost every case due to the loss of his perceptive abilities. In almost every case stereopsis (depth perception) is affected. Fortunately, the condition is usually self-limiting or in rare instances with the use of steroids or laser beam surgery nearly all of these individuals have been returned to the cockpit and have performed effectively.

Mainly, the majority of individuals referred under the cornea category had medical/corneal conditions that necessitated a contact lens to improve the vision so that they could be returned to flying status. Once again, contact lens research paid off since the majority of these individuals were likewise returned to the cockpit. With the improvement in contact lens, there is a need for research on the applicability of the soft contact lens, in the aviation environment. It would further be important that this lens be an extended wear lens, having the possibility of being

worn for at least a week without removal; and secondly, this lens should also have the capability of correcting astigmatism since sharp vision is a necessity for the aviator.

In the motility area the recent attention to the entity of microtropia (microstrabismus) reinforces our previous statement that there is a need to know just which visual parameters are important to the aviator. Microtropes were discovered because they lacked stereoacuity, i. e., they lacked stereo of sufficient acuteness to pass the present stereoscopic (depth perception) criteria. The research we envision here is determining just how many seconds of arc disparity in the stereoscopic examination should be disqualifying for the flyer.

The two neurologic disorders of multiple sclerosis and migraine are devastating to a flyer's career since once the diagnosis of these conditions is made, presently, the aviator is grounded with no chance of return to the cockpit. There is a need to attempt to identify which patient is most likely to have a recurrence, and if there are any classic signs or testing procedures that could separate the mild from the truly visually incapacitating cases.

Finally, as the aircrew population ages, the problem of cataract needs to be looked at. To date, most of the Air Force flying personnel who have had cataract surgery have been permanently grounded. At the USAF School of Aerospace Medicine we have commenced a small study group observing aircrew with monocular operated cataracts, with vision corrected by contact lens. Further, as more cases become available, flyers with the newer plastic intraocular lenses should be evaluated as to the aviation hazard potential of such a device and its effectiveness in correcting the monocular stereoscopic defect.

PROTECTION AND ENHANCEMENT OF THE FLYER'S VISION

There is a need to look at better materials for spectacle lenses so as to provide more protection than is presently available with the CR-39 plastic lenses or the heat or chemically treated glass lenses. One such material is the polycarbonate lexan. The Optical Research Laboratory of the Ophthalmology Branch at USAFSAM is looking at corrective lexan lenses in aviator's frame in a field project. Unfortunately, even though these lenses are coated for scratch resistance, haze and scratching are showing up at a much more rapid rate than in the CR-39 companion lens. Research here should probably be directed towards coatings that would allow a useful life at least as long as the CR-39 plastic lens. Even though the present aviator spectacle frame HGU-4/P has served exceedingly well for two decades, because of the high cost of gold which is used in this frame, there is a need to look at other materials as a possible replacement for this item. Plastics which were not available when the original frame was designed should be considered. The Optical Research Lab, at USAFSAM, is looking at a new non-allergic type plastic, optyl, as a possible subsitute frame material.

Protection against lasers and against flash blindness is presently available. There are filters that protect adequately against known individual lasers and the PLZT flash blindness goggle appears to be able to give adequate protection against both flash blindness and retinal burns from thermonuclear weapons. The problem is that these are all cumbersome and restrictive items which are not compatible with the high G-forces that are and will be generated in the new generation fighters. Therefore, research now in these areas is needed to lighten, miniaturize, and integrate these protective devices into the least restrictive-type visor imaginable. Otherwise, the visual tradeoff will be more than can be accepted.

MACHINE

In the chain of optical devices that interfere with the pilot's vision, one also must consider the windscreen of the aircraft, since this transparency must be looked through by all pilots whether wearing spectacles and other protective devices or not. Flat, parallel pieces of glass cause the least distortion and restriction to vision. However, newer aircraft with shaped contours and designed for increased performance made low profile, sloped windscreens a necessity. Further, the high speeds attained at low attitudes made birds as formidable an enemy as other aircraft. The US Air Force Windscreen Evaluation Program, which was begun in the Ophthalmology Branch at USAFSAM and is now being continued at the Aeromedical Research Laboratory at Wright-Patterson AFB, has been successful in upgrading the optical quality of the plastic laminated windscreens which replaced the original glass models. Further research in this area continues to be necessary, however, in attempting to extend the life of these very expensive transparencies. Therefore, one will have to look at other coatings, newer laminates, and perhaps methods of resurfacing rather than replacing the windscreen.

An opposite approach should also be considered, i. e., one of studying the maximum amount of degradation acceptable by the pilot and yet be able to perform his mission. Attempting to achieve the perfect transparency is obviously unnecessary and, further, would be prohibitively expensive.

ENVIRONMENT

The universal problems of hypoxia and dsybarism on vision in the aviator are adequately handled by the present oxygen and pressurizing systems in modern aircraft. The potential for higher G-forces has gone up markedly in the new generation fighter aircraft. Human physiology has not changed; however, better valves in the anti-G suits and rigid training in the M1 and L1 maneuvers have extended the G capabilities of USAF fighter pilots into the 8 to 9 G range. This obviously allows better utilization of the increased capabilities of modern generation aircraft. However, the effects of these increased G-loads on the visual and perceptive capabilities of the fighter pilot have not been adequately studied. A project was started at the USAF School of Aerospace Medicine to evaluate the effects of these high sustained Gs on central visual acuity. However, this was never completed. Such studies should be undertaken so that the overall capabilities of the pilot when under these extreme physiologic demands can better be assessed.

And, finally, we will consider a new threat to the visual system brought about by environmental changes previously not considered to affect the aviator. These are the toxic gases that might be the result of chemical warfare. The nature of such chemicals could make them profoundly felt on all aspects of flying since most of these agents affect the eye and vision. Most of the presently known nerve gases are organophosphates or acetyl cholinesterase inhibitors. Cholinesterase inhibitors can profoundly affect vision even in extremely small doses. Agents similar to the war gases are presently used to treat glaucoma and they all have side effects on the iris and ciliary muscles causing extreme miosis as well as ciliary spasm and thereby fairly marked myopia. One can see then that even small doses of these nerve gases could cause marked alterations in the night and distance vision of the pilot. This would obviously markedly impede mission accomplishment. Research is necessary in the area of quantifying the minimum dosage that would bring about such visual changes in the eye. Further, a search should be made for mimetic drugs that act similar to the toxic agents but are not toxic themselves and in this man-

ner would allow simulator studies to be done to more accurately evaluate the effect of these drugs on degradation of the mission. It will be necessary to look into more effective masks as well as antidotes and protective medications.

In the Ophthalmology Branch at USAFSAM the research on the visual problems of the flyer began 60 years ago by Colonel William H. Wilmer and Major Conrad Berens, and this has continued over the entire existence of the organization. It can be seen that the changing parameters and demands of the mission have always outdated and outdistanced the research and accomplishments, so from past experience it is expected that this trend will continue as long as there is any change and progress in aviation.

HUMAN FACTORS VISION R&D PROGRAM AT NAMRL

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INTRODUCTION

In June 1973, the Navy's Human Factors vision R&D program was established by joint agreement between the Bureau of Medicine and Surgery and the Naval Air Systems Command. The Naval Aerospace Medical Research Laboratory was designated lead medical department activity for this program, and was authorized at that time to develop a program plan and to begin the development of appropriate laboratory facilities.

A. Objectives

The objectives of this program are to (1) identify visual requirements in naval aviation which limit mission effectiveness, (2) investigate and define the critical visual functions relevant to these requirements, (3) develop methods for improving visual screening and/or for enhancing required visual capabilities through training, and (4) develop improved criteria for the design of visual displays.

B. Approach

The approach to meeting these objectives includes the following steps where practicable:

1. The User identifies the problem and requests R&D assistance. Among the Users are various offices of the Chief of Naval Operations, Naval Air Systems Command, the Bureau of Medicine and Surgery, the Chief of Naval Education and Training, Naval Training Equipment Center, Naval Air Development Center, and most importantly operational and training squadrons in the fleet.

2. Assist the User in analyzing the stated problem and specify aspects of the problem for which R&D efforts may be useful.

3. Develop quantitative measures to assess current performance capabilities related to the problem. This assists in further problem definition, and provides baseline data against which the benefits of recommendations from R&D may be judged.

4. Assess available information related to the problem, and apply state-of-technology techniques to improve performance.

5. Develop quantitative assessment of performance with improvements, and compare with baseline measures.

6. Specify recommendations, methods for implementing them, and estimated benefits from implementation.

7. Identify technology gaps and gaps in the state-of-knowledge related to the problem, and address these as part of the longer term laboratory program.

REQUIREMENTS

The following are current R&D requirements which have been identified by the User community, and which are at various stages of development by the NAMRL vision program:

A. Visual Screening Standards

Current vision tests have not been validated against job related criteria. Further, these tests do not include assessments of visual functions which are considered to be of great importance to visual performance required of naval aviation personnel. Examples of these untested functions are peripheral detection, dynamic acuity, and resolution of low contrast targets. Goal: Develop and validate a battery of vision tests for assessing visual functions which limit mission effectiveness in naval aviation.

B. Effects of Age/Experience Upon Visual Capabilities

Naval aviators are automatically reclassified from Service Group I to Service Group III at age 45. This administrative action is based, in part, upon assumed changes in visual capabilities as a function of chronological age. There are great individual differences in susceptibility and rate at which these changes occur. Goal: Develop age/experience criteria for assessing aviator visual capabilities throughout career assignments.

C. Air-to-Air Visual Target Acquisition

Tactical advantage in air-to-air combat depends upon early visual acquisition and continued tracking of airborne targets. There is great variability among fleet aviators in their abilities to visually acquire other aircraft. Occurrences of midair collisions and near misses under VFR conditions are costly in lives and material. Goal: Develop methods for improving fleet

capabilities for air-to-air visual target acquisition by means of specialized visual screening and visual training techniques.

D. Visual Requirements for Carrier Landing

Accidents and incidents during carrier landings occur more frequently during night than day operations. Major task differences between night and day operations are visual. Goal: Identify critical visual cues required in carrier landing, and develop methods for enhancing those cues during night operations. Identify visual/perceptual capabilities required for carrier landing performance, determine their relationships to night vs day performance, and develop specialized visual screening criteria for carrier aviation.

E. Advanced Display Criteria

The majority of military specifications and standards concerning the visual characteristics of displays are based upon "expert opinion" and convention, rather than upon data. Of the specifications which are based upon data, virtually all are concerned with reflective rather than self luminous stimuli, and with real images rather than virtual images. Display hardware technology is advancing faster than is knowledge of how best to use it. Advanced display technology is being proposed and implemented without adequate information about consequent visual requirements. Particular examples are Head-up Displays and Helmet Mounted Displays. Goal: Assess visual characteristics of advanced display designs, and test assumptions upon which they are based. Determine assets and liabilities of new displays relative to visual performance of aviation related tasks. Develop criteria for advanced display design based upon visual requirements.

F. Scan of Visual Displays

Visual task loading in many aviation systems is excessive. Significant time is devoted to the visual scanning of cockpit displays, and this scanning is generally performed inefficiently. Goal: Define visual display characteristics which impact scan efficiency, and develop design criteria which serve to enhance scan performance. Develop methods for training aviation personnel to perform visual scan requirements more effectively.

G. Simulation Displays

Capabilities for meeting current and anticipated ground-based aviation training requirements depend upon the simulation of visual reference outside the cockpit. The characteristics of the outside visual environment upon which aviator performance depends have not been identified. The various technological approaches to this simulation offer alternative strengths and weaknesses. Goal: Identify outside visual cues which are critical for valid aviation training. Evaluate relative strengths and weaknesses of current simulation technologies. Develop visual design criteria for simulation of outside reference.

PROGRAM

The goal in program and facilities development is to provide a capability with sufficient breadth to be directly responsive to a wide range of Navy problems, and sufficient depth to address these problems at as fundamental level as their definition will allow. Thus, responses to immediate User problems may be developed from the current state-of-technology, while more generic information is being developed to advance the technology base.

The NRC Committee on Vision has provided invaluable assistance and counsel in the development of a program and facilities to meet the above requirements. In addition to the considerable informal counsel obtained through this committee, the following formal working groups significantly influenced program development.

Working Group 39.	Standards for Testing Visual Fields and Visual Acuity.
Working Group 40.	Visual Detection of Air and Ground Targets.
Working Group 41.	Procedures in Testing Color Vision.
Working Group 42.	Ocular Effects of High Intensity Lights.
Working Group 43.	Visual Problems of Virtual Image Displays.
Working Group 44.	Effects of Visual Experience on Distant Vision.
Working Group 46.	Misleading Visual information in Night Landing Approaches.
Working Group 55.	Visual Changes in the Aging Process.
Working Group 56.	Air-to-Air Visual Search.

The following is a brief description of program facilities and the nature of the work for which each is utilized:

A. **Vision Test Battery (VTB).** In addition to the tests currently used for screening, NAMRL's experimental Vision Test Battery provides some fifty psychometric and optometric tests which include dynamic responses to both high and low contrast stimuli, in both the central and peripheral visual field. Current work will determine the reliabilities of these tests and the correlations among them. Next, the distributions of visual abilities measured by this battery will be determined for a representative sample of aviation personnel. Finally, the tests will be validated against aviation related performance criteria as determined by user requirements.

B. **Head-Up Display (HUD).** The Head-up Display facility provides for the presentation of "outside" visual stimuli simultaneously with "display" stimuli at controllable distances and angles of declination. A major motivation underlying the development of Head-up Displays is to save the time required in looking inside the cockpit and out again during critical mission segments. Current work in the Head-up Display facility tests the assumption that time is saved by a HUD configuration, and investigates the relationships of visual and oculomotor performance measures to performance of aviation related tasks. A portion of this investigation will include direct observation of these oculomotor responses using the Binocular 3-D Eye Tracker facility (below).

C. **Functional Visual Field (FVF).** The Functional Visual Field facility provides for the monocular presentation of a positive contrast disk over a hemispheric field of 180°, and the independent presentation of an arbitrary visual stimulus in the center of the field. Peripheral vision is considered to be important to general locomotion and orientation, and in particular to visual search and scan performance. Further, the modeling of search behavior, or the design of a crew station requires certain assumptions regarding the size and sensitivity of man's visual

field. Estimates derived from clinical perimetry are seriously misleading for task loaded applications because the effective visual field shrinks when the observer is even mildly stressed either physically (heat, cold, anoxia) or psychologically (simultaneous task). Current work is investigating the characteristics of a central visual task which affect the functional visual field, with the goals of estimating FVF changes under the aviation related conditions, assessing individual differences in susceptibility to visual task loading, and developing methods for non-intrusive assessment (VER) of peripheral visual functions.

D. Binocular 3-D Eye Tracker (BIDETS). The 3-D Eye Tracker facility employs a state-of-technology optical system for tracking eye position and accommodation, and for controlling the optical position of virtual image stimuli in 3 dimensions. The tracker is capable of measuring X-Y eye position with accuracies better than 1 minute of arc, and accommodative state within 1/4 diopter. The stimulator is capable of presenting virtual image stimuli at any position within a 25 degree field, and moving them in three dimensions with speeds and accuracies comparable to those of the eye. Further, the observer has an unobstructed view of a 40-foot visual range in which real visual stimuli may be presented. This is a particularly powerful facility for investigating the mechanisms of binocular responses to stimuli in three dimensions. Immediate work in this facility will include the quantification of oculomotor responses to aviation related tasks involving head-up displays, the investigation of stimulus characteristics which enhance or degrade fixation and accommodation responses, and the development of a method for the voluntary control of accommodation. Longer term efforts will investigate fundamental issues in oculomotor control and binocular interaction, with direct servo control applications ranging from prosthetic devices to weapons systems.

E. Dynamic Visual Acuity (DVA). The Dynamic Visual Acuity facility provides a high degree of control over stimulus variables for the presentation of moving targets. The target is presented against a circular screen of 18 feet radius, 170° azimuth and uniform brightness (± 4%), and is moved at angular rates up to 1000° sec (± .1%) with respect to the observer. The task is to detect, track and resolve the target, all within .4 seconds exposure time. Of the visual tasks previously investigated, this one appears to offer the greatest potential for predicting visual performance in aviation missions, on the one hand, and for investigating visual acquisition processes, on the other. Present experiments are indicating that acquisition cues may be manipulated independently of resolution cues, and that performance may be improved with practice far more than has been reported previously. Future work will investigate the stimulus characteristics which enhance and/or degrade visual acquisition, the nature of observed individual differences in this ability, and the characteristics of eye movement responses which relate to successful performance. This work will have direct applicability to the development of visual screening criteria and the development of design criteria for visual displays. This effort will be supported by corroborative experiments utilizing the 3-D Tracker (above) and the Optokinetic Response facility (below).

F. Optokinetic Response (OKR). This facility provides continuous movement of visual stimuli mounted on a drum of 5 feet diameter which rotates about the observer at angular speeds up to 600°/sec. (± .1%). The drum is diffusely illuminated and is viewed from its center of rotation through a variable aperture. A reflexive, orienting response to such stimuli appears to be near universal among visual animals. In man and most animals having mobile eyes, a nystagmic eye movement response is elicited. Work in this facility is derived from the hypothesis that the visual mechanisms which drive the optokinetic response are fundamentally related to visual orientation and to the visual acquisition process. Specific hypotheses will be tested in

conjunction with Dynamic Visual Acuity experiments. Microelectrode experiments will search for visual cells which behave according to these hypotheses under similar stimulus conditions.

G. **Visual Target Acquisition System (VISTAS).** This is a unique facility for providing a controlled visual environment similar to the airborne environment. The observer is seated at the center of a circular screen of 30 feet radius, 224° azimuth, and 39° elevation. The retroreflective screen is illuminated by a single source mounted on his helmet to produce near uniform brightness up to 800 ft. L. Positive contrast stimuli are provided by a projector mounted on a rate table directly above the observer. Stimuli may be projected in any position on the screen, or moved in any desired path by control of the rate table (azimuth) and a motor driven mirror (elevation). This facility will provide capabilities which have not been achieved previously for investigating visual problems in aviation. Work in this facility will address critical issues in air-to-air visual target acquisition including characteristics of visual search and accommodative responses in a large, bright visual field, issues related to Head-up and Helmet Mounted Display design criteria, visual requirements in carrier landing, and visual scan/time share training.

H. **Vision Detection Simulator (VDS).** The Vision Detection Simulator consists of a Supervisor's Console, a Link GAT-1 trainer, 14 pairs of projectors, and some 30,000 35mm slides from inflight photographs. The pilot's eye position is at the center of a spherical projection screen of 15 feet radius, 176° azimuth, and 25° elevation. The projectors provide an inflight scene composed of fourteen high resolution color slides, in one of which is represented a target aircraft. This facility offers a realistic representation of inflight visual scenarios together with aviation related performance tasks, and is used to investigate characteristics of visual scan and search performance during simulated flight. Another major role of this facility will be to provide a vehicle for "intermediate" validation of results from other laboratory experiments. As information is obtained from other facilities which appears to be applicable to the inflight visual environment, this applicability will be tested in the VDS and/or the Visual Target Acquisition System before attempting an inflight field validation.

THE US ARMY AEROMEDICAL RESEARCH LABORATORY VISION RESEARCH PROGRAM

LTC John K. Crosley
RESEARCH OPTOMETRIST

U. S. ARMY AEROMEDICAL RESEARCH LABORATORY (USAARL)

The US Army Aeromedical Research Laboratory (USAARL) is one of the eight laboratories under the command of the US Army Medical Research and Development Command located in Frederick, Maryland.

It is an organization formed to conduct basic and applied research in medical and applied sciences. The research is directed toward the solution of aviation, armored vehicles, artillery, and airborne medical problems encountered by the Army.

The purpose of the research is: (1) to develop a better understanding of the aircraft environment and its effects on the aircrew; (2) to improve the safety and efficiency of Army aviation operations; (3) to evaluate aviation and combat crew medical problems encountered by the Army which are often basically different from those experienced by similar organizations; and, (4) to determine the hazards of nonmedical materiel.

This research is accomplished through in-house independent laboratory research programs, consultation with recognized authorities, experimental studies in the field, cooperative studies with other military and civilian organizations, universities and commercial research contracts, and the exchange of technical information with foreign armed services.

At present, USAARL has approximately 150 personnel with both civilian and military about equally distributed. Some of the specialities represented are: aviation medicine, environmental medicine, internal medicine, biophysics, bioengineering, biochemistry, biomechanics, experimental and sensory psychology, audiology, physiological optics, neurophysiology, and veterinary medicine.

Fort Rucker is located in the southeastern corner of Alabama approximately equidistant between Montgomery, Alabama, and Panama City, Florida. It is the home of both the US Army Aviation Center and Aviation School. Essentially, all rotary wing aviators in the military are presently trained at Fort Rucker along with a number of foreign flight students.

Although the laboratory has been located in a number of "temporary" barracks-type buildings since being established in 1963, a new laboratory is presently under construction and due for completion in July-August, 1980.

Vision research has constituted an important part of the overall program at USAARL. One of the laboratory responsibilities is to provide technical expertise to local Operational Test (OT) and Developmental Test (DT) agencies as they evaluate new pieces of equipment or systems. Vision support might involve analyzing the windscreen for reflections or distortion or measuring instrument lighting for balance and overall acceptability. Reflections from instruments at night can be a hazard to safety as well as being annoying to the crew.

The optical integrity of any transparency employed by military personnel must be excellent, whether it be a helmet visor for aviators, a protective mask, dust goggles, corrective lenses, or any of a number of items. An optical evaluation of this type of equipment can be conducted in the laboratory or in the field, although field studies tend to be somewhat less sophisticated.

The visual workload for aviators performing specific tasks is considered important for a number of reasons. A modified NAC Eye Mark Recorder used in conjunction with a LOCAM high-speed camera has been employed by this laboratory to determine the visual workload for pilots as they perform certain missions. The recording of the pilot's point of fixation on film is a technique used to examine the visual time spent inside the cockpit looking at flight and engine instruments, time inside the cockpit on the map and other navigational aids, and time spent outside the cockpit including the area of the windscreen most frequently utilized. For example, during low level flight over unknown terrain, it has been shown that only 3% of the total time available to the pilot was "free", and that the duty of navigation required 92.2% of the copilot's total visual time. Only 4% of the available time was spent looking at engine and flight instruments.

Aircraft, especially those painted Army "green," are difficult to see in the daytime. A great deal of time has been spent trying to improve the overall conspicuity of aircraft. This has been done by developing specific paint patterns for application to fuselage, main and tail rotors; and by developing a xenon gas-filled discharge tube (so called "strobe") light designed to provide visual information in the daytime. This new system, termed Army Anticollision Beacon System High Intensity Light (AABSHIL), is presently completing first-article testing and is likely to be applied to a number of DOD aircraft as well as those of several foreign nations.

An effort to develop a new all-inclusive protective mask (XM-29) by the Chemical Systems Laboratory has been ongoing since about 1970. USAARL was asked to perform an optical evaluation of this new coated silicon rubber mask. This mask is designed utilizing a new concept for the facepiece--a design not without optical problems.

In conjunction with the XM-29 development, it was decided to develop a different system for providing corrective lens wear--something other than the previous insert method. A spectacle frame was designed which incorporated a very thin temple strap which, due to rigid construction, could be used as a "combat" frame as well.

A technique, similar to that of Dr. Henry Knoll, has been used to measure "nocturnal myopia" for aviators. This system, using a low-power laser, has proven to be workable in the laboratory. There is, however, a lack of information concerning what, if any, effect this condition might have upon performance. There is also some question concerning the amount of correction that should be prescribed for individuals exhibiting this ametropia.

The AN/PVS-5 Night Vision Goggles were developed originally for ground personnel to enable them to engage targets under subdued night-time luminance. A decision was made several years ago to use this same device for aviation. USAARL has spent considerable effort trying to resolve some of the existing problems associated with wearing the mask while operating aircraft. These include weight and center of gravity, poor resolution, focusing for near tasks, compatibility with aviation headgear, color vision changes (map reading), changes in stereopsis, and utilization in the daytime for training purposes.

The introduction of the AH-64 Army Attack Helicopter has pushed both aviation technology and the human to their limits. This aircraft was developed for day, night, adverse weather, anti-armor missions under field conditions. It incorporates, among others, a Target Acquisition Designation System which uses daytime TV, forward looking infrared (FLIR), direct view optics and a laser designator in addition to a Pilot Night Vision System using primarily FLIR. The FLIR imagery is observed by the pilot on a helmet-mounted display known as the Integrated Helmet and Display Sighting System (IHADSS) which keys the Pilot Night Vision System turret movements to the movements of the pilot's helmet through the use of electro-optical sensors. This laboratory has been deeply involved in the developmental efforts for the IHADSS. Using an assigned UH-1M research helicopter with a low light level television system installed, laboratory personnel have been addressing many of the technical problems associated with this sophisticated system. One such basic problem involves use of the head as an aiming/tracking device. Using a man-rated vibration platform capable of reproducing the vibration spectra of an attack-type helicopter, subjects were required to track multiple-array targets with the head while performing additional routine tasks. The results indicate that improving the man-machine interface with more comfortable and better-fitting helmets and selectable sighting eye will not enable the man to significantly improve his head aiming/tracking capability. The study also shows that target speed was a very important factor when considering tracking errors.

The role of lasers in the military environment is still somewhat unclear. They are used for multiple purposes and range the full gamut in terms of output. Perhaps the clearest fact is that virtually all of them present a threat to the physiological integrity of the eye. Of course, in some instances the ocular damage threat is of little relative concern considering the overall body damage risk. For the past 15 years, we have all been aware of the potential risk to the eye presented by most lasers. From the Army standpoint there has been relatively little research conducted over these years to develop a device or method for eye protection. USAARL has not been actively engaged in research directly associated with lasers or laser protection although our vision personnel have functioned as consultants upon request. Letterman Army Institute of Research has a team primarily involved in conducting basic damage risk research and providing information for the development of military standards. The Army Environmental Hygiene Agency has a group charged with the responsibility of applying these standards to fielded weapons and designating their relative hazard. There are still a number of unanswered questions about lasers and the role they may (will) play in future engagements.

An interesting research endeavor recently pursued concerns the relationship (if any) between fatigue and dynamic visual acuity (DVA). A compact, field-portable unit for measuring DVA was constructed and utilized in a research program designed to evaluate biochemical and psychophysiological measures of fatigue. This fatigue was produced by a continuous operation regimen involving some 12 hours of flying and 3 1/2 hours of sleep daily for 5 days. The DVA portion of the study showed relatively small variations in performance throughout the study.

It also showed that fatigue effects were generally obscured by the effects of practice--a factor observed in other measures of oculomotor performance.

It is difficult to perform in-flight observations from air-to-ground with the naked eye. A standard pair of binoculars employed as an aid in this task frequently leads to headaches or airsickness or both. To investigate any correlation between airsickness incidence and optical devices used to make air-to-ground observations, a joint in-flight research effort was performed by the Naval Aerospace Medical Research Laboratory in Pensacola, Florida, and USAARL. Using an active (electrically powered) 7X power stabilized system, in-flight results indicated that whenever a magnification device (whether stabilized or nonstabilized) is used in this role, airsickness incidence will rise according to the basic airsickness susceptibility of each viewer. Whereas previous theories stated that stabilization tended to increase the incidence of airsickness, these studies showed this to be incorrect under these conditions. Subsequently, USAARL evaluated a series of hand-held optical magnification devices in-flight to establish their relative merit. The units were in the 8X to 10X power range, monocular, and included both active and passive stabilization. Although the active units evaluated performed well, they were characteristically heavy and due to the electronic circuitry, required more maintenance. The recommended unit was passive and performed essentially as well as the more cumbersome active units.

Contact lenses have been of military interest since 1943 when a short study was conducted at Fort Knox, Kentucky. In 1972, USAARL personnel evaluated the potential application of the Bausch and Lomb "Softlens" to the aviation environment. Although not deemed totally acceptable, the study did show that the incidence of foreign body involvement with this soft-type contact lens was not a problem when worn in the vicinity of helicopters and flying dust particles. It also showed continuous wear of up to 72 hours was feasible. Currently, a study is being conducted to evaluate a new type of soft lens to be continuously worn for a longer extended period - one week.

LTCOL JOHN K. CROSLEY

DISCUSSION

DR. RANDOLPH: I will say that it is time that we in the services start putting some pressure on those agencies and those elements that are responsible for the production of goggles, for the production of personal safety equipment.

LTCOL CROSLEY: We are going to try to pull everybody together and start a centralized coordinated effort towards the resolution or attempted resolution of the problem.

CONTACT LENS

LTCOL CROSLEY: We have a contact lens program. This is the second time we have looked at the application of soft contact lenses in the aviation environment. The first one was in 1973 when we looked at the Bausch & Lomb soft lens and found no problems with foreign body involvement, and we were able to get up to 72 hour continuous wear with these lenses. Now we are taking a look at a new lens on the market of a different material for a period of wear up to a week. Hopefully, we will have some data to record in that regard before too long. We have a total of 42 subjects.

DR. CHISUM: Colonel Tredici, are you permitting your pilots to wear contact lenses currently?

COL TREDICI: Well, we started a medical type program. We have rehabilitated half a hundred individuals who have a medical problem that the hard contact lens was the answer to. The soft contact lens we have not looked at it mainly because we analyzed what was going on in the field thanks to the first project done by the Army and decided that it wouldn't be worth our while because of several inherent problems in the lenses which were available, some of which have nothing to do with seeing. The paraphenalia that has to go along with the lens and the cleansing and the sterility makes a bigger hassle than the primary task that the navigator or pilot has to perform. We don't see any soft lenses on the horizon that will cure the problems that we want tackled, that is, the correction of acuity.

DR. CHISUM: Corneal problems?

COL TREDICI: Yes, the astigmatism; the correction of acuity as good as or better than spectacles. Now, everybody talks about the hugh visual field. But if you noticed today, everything was talked about. The visual field of the pilot is about 15 degrees, spectacles easily encompass that.

LTCOL CROSLEY: I might mention that the driving force in the Army for the utilization of contact lenses is the introduction of some very sophisticated visual or optically-generated sighting devices, which preclude the utilization of spectacles.

DR. WOLBARSHT: This is to Colonel Tredici. Have you any experience with the use of contact lenses to reshape the cornea? I know people do it all the time. I just wondered what your participation is in these programs.

COL TREDICI: Very quickly, we have observed this reshaping, orthocaritology, which sounded fabulous because you could redo the man. That would save all these problems that we are talking about here. Unfortunately, it hasn't worked out quite as well as had been anticipated. If you reshape the cornea and take the lens away, it's going to bounce back. If it doesn't bounce back, then you have probably got some pathology and it will become worse than it was in the first place. The only way you can maintain any gain is by continuing to wear the lens.

MONITORING EYE MOVEMENTS FOR WIDE-ANGLE VISUAL DISPLAYS

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There are several presssures to extend simulator-based flight training to tasks for which aircraft have previously been used. These are tasks like air-to-air and air-to-ground tactics, low-level flight, and target acquisition that are either dangerous or costly to train using aircraft - particularly in terms of the amount of flight time devoted to the actual training - or both. These tasks differ from the landings and takeoffs that traditionally have been trained using simulation devices in that it is necessary for the pilot to appreciate a variety of events occurring about him and it is anticipated that fairly wide field-of-view visual displays will be needed for effective training. Currently two technologies are competing to provide such wide-angle displays - one is to surround the cockpit with a mosaic of large cathode ray tubes which present an out-the-window image of the world, and the other is to project images on a dome surrounding the cockpit. In order to train these tasks effectively, targets (either on the ground or in the air) must be detected, and to do this, the resolution of their images must be fairly high. It is the problem of obtaining this level of resolution in a cost effective manner that is the subject of present research and development work.

The CRT systems typified by the Air Force's Advanced Simulator for Pilot Training and the Simulator for Air-to-Air Combat present images of uniform resolution on each CRT face, with wider fields of view achievable by adding more such channels, yet these display systems are expensive and delicate. Dome projection systems have approached the problem of high resolution images by having at least two projection channels - one to display a low-resolution background spread over the entire field of view and a second to insert high-resolution images of objects of interest. Currently such systems present fairly detailed images of objects given that the location of that object relative to the pilot is known. Thus, the present inserted area-of-interest displays show objects on the land or sea or other aircraft.

Ideally, the ability of a display system to produce high-resolution images of limited size should be directable by the needs of the pilot being trained, i.e., he should be able to examine any object in his visual world (external to the cockpit) to determine if it is a threat or a target. The Naval Training Equipment Center is currently pursuing several projects related to the development of such capability for flight training devices. One such project is the development of an area-of-interest computer image generation system where the number of pixels per raster line can be variable. This would allow a computer generated image of non-uniform resolution to be formed where the area of greatest pixel density could be placed wherever needed. Another

project is to perfect a helmet mounted projector for images to be projected onto a dome so that distortions arising from the differences of position of the pilot's eyes and the projection source are minimized. While the goals of such projects are to improve the visual displays for flight training, to reduce the size of simulation devices, and to make them more cost effective, the topic of this paper is some of the visual problems we anticipate in these developments.

Perhaps the main problem is created by the task of allowing the subject to determine the location of the high-resolution area of the displayed image. This requires that his point-of-gaze determine the center for the high-resolution insert and the real problem is the mechanization of such a capability. It would involve the tracking of both the position of the pilot's head and his eyes, and in real time the calculation of the direction of his gaze. Fortunately, some of this problem (for the most part) has been solved. There are operational head trackers which can monitor the position of the head in three rotational degrees of freedom to an accuracy of about 0.5 degrees. They operate by having a source create a nutating magnetic field in three axis and sensors mounted on the pilot's helmet are used to measure the relative angle between themselves and the source. Such systems operate quickly with system delays less than 20 milliseconds, and as the head rarely exceeds velocities of 300 degrees per second, monitoring the position of the head with a tolerable degree of accuracy should be little problem.

Tracking the position of the eyes in a fashion suitable for training situations does pose more of a problem. The high accuracy achievable by some techniques of eye monitoring (Young and Sheena, 1975) may not be needed, but neither are some of the optical arrangements needed for the measurement. Simple infrared detectors can monitor the horizontal movements of the eyes to a degree or so, but vertical eye position poses a problem which may require some development work. For vertical measurements, the infrared detectors monitor the position of the lower or upper lid, but these can move with different dynamics than the eyeball. Regardless of the final measurement technique used, eye position in two rotational degrees of freedom will be needed to determine the point of gaze.

Perhaps of more technical interest is the need to predict a new point of gaze once a change of gaze is detected. The reasons for this need are related to the sequence of operation of the various subsystems of a flight simulator. These devices iteratively sample the positions of the various controls in the cockpit and then calculate the response of the aircraft to these inputs. In newer systems, this happens typically at 30 samples per second. If a computer image generation system is used to form the images for the visual display, the new position of the aircraft is calculated and is then passed to the image processor which calculates an appropriate picture. These processors can operate at 30 Hz and take about three frame times (about 100 milliseconds) to produce a new image, so that the time between pilot input until the displaying of the aircraft's responses can usually exceed 120 milliseconds. The Naval Training Equipment Center's visual technology research device can operate at 60 Hz, if necessary, which would almost halve that time. Obviously for an area-of-interest image generation system, any means of providing the system the coordinates of a new point of gaze before the eye arrives there would reduce the delay with which an appropriate new images would appear on the pilot's display.

Several metrics for such prediction are under consideration, but few data exist that could give an indication of how accurately resting eye position can be predicted. The velocity waveforms of saccades are roughly symmetric - suggesting that a metric like peak velocity could be used, at least until that starts to level off at velocities of 550 to 750 degrees per second. In the same vein, the velocity at the peak positive acceleration could also be a metric for prediction.

These measures have the advantage that they are relatively easy to obtain, but no data exist that might indicate how well they might reflect the resting position of the eyes after a saccade. Some data do indicate the variability of peak velocities and accelerations for saccades of fairly fixed size though (Boghen, Troost, Daroff, Dell'Osso & Berkett, 1974; and Fricker and Sanders, 1975). Some thought has been given to stabilizing a metric by averaging or filtering (Anlicker, 1976), but until data can be obtained, these remain problems of unknown magnitude. Also, should subjects display considerable individual differences of these measures for saccades of similar size and direction, the extent to which these differences may correlate with other measures could aid the development of an automated tracking system.

The degree to which head and eye position can be accurately and somewhat inobtrusively monitored will determine the feasibility of controlling the location of a high-resolution area of a visual display by the pilot's interest. How well the resting point of gaze can be predicted and when, during an eye movement such information would be available, will affect the appearance of such a visual display. Given that the appearance of the area of interest will be delayed by some amount - how much to be determined - how perceptible this delay would be, and if so, how aversive or disruptive it may also be is still to be determined. Long delays in manual control systems certainly affect pilot control performance (Ricard and Puig, 1977), but we know of no comparable data for the tracking of visual targets. Tracking is not really the problem though as the intention is not to present a target which the pilot must track but to allow him to determine where in the visual scene he would like more detail. It is the delay of that information which may be noticed and which could disrupt his scan pattern, for instance, in target acquisition tasks.

Again we know of no data related to this question, but we are preparing to investigate it at the Naval Training Equipment Center. Briefly, a two-gun CRT will be used to present a fixation point and a moveable target, and delays of various durations can be inserted into the movement of the target. The task initially will be to saccade to indicators at various distances from the fixation point and to report if a delay was present or not in the tracking of eye position by the target. Normal forced-choice psychophysical procedures will be used to determine thresholds as a function of variables like the size the saccade or the size of the target and its relative contrast. Some very preliminary but encouraging observations indicate that delays below 100 milliseconds may not in fact be very noticeable.

Most of us worrying about the delayed appearance of a part of a visual scene that is tracking eye position suspect that saccadic suppression - the attenuation of vision during rapid movement of the eye - will operate to make these display systems more acceptable than if there were no such suppression. Estimates of the time course of saccadic suppression shown in Figure 1 (taken from Volkman, 1976), indicate a period of 100 to 150 milliseconds after the start of a saccade before visual thresholds have returned to normal. Clearly changes occurring to the visual scene will be less noticeable than normal during that period. The question we need to answer is how much less and is it enough. To this we presently have no answer, the reviews of the suppression literature (Volkman, 1976; Matin, 1974) are encouraging. To the extent that part of the display may move (as in an area-of-interest projection system, for instance), until such movement is large relative to the size of the saccade, it may not be noticed (Bridgeman, Hendry, and Stark, 1975; Stark, Kong, Schwartz, Hendry, and Bridgeman, 1976). For an area-of-interest computer image generation display system, image movement may be less of a problem.

Another set of questions about the design of a moveable area-of-interest display concerns the size of the high-resolution insert. One argument is that it probably need not exceed foveal

dimensions in that visual acuity falls sharply outside the fovea, yet a literature is accumulating indicating that, at suprathreshold levels of brightness, information can be processed from a much larger area - of about six to eight degrees or more. The size of this "functional field of view" - where information can be extracted from a visual display - seems dependent on the density of irrelevant items in displays containing discrete elements (Mackworth, 1976), and on the size of the scene to be processed (Saida and Ikeda, 1979). It is probably a function also of the sort of visual information the observer needs from a given visual scene. The point is that quite likely an area larger than the fovea would benefit from being displayed with greater resolution.

A last problem for the development of an area-of-interest display concerns the allocation of system bandwidth over that portion of the image which will track the point of gaze. One of the motivations of projects of this nature is to reduce the total system bandwidth needed for wide angle display systems to a level where special purpose components would not be needed. It was from this point of view that the present area-of-interest displays developed - the ones where the area of interest is defined by an object in the visual scene. They use a uniform resolution across the insert and a lower uniform resolution across its background, yet this need not be the case. For a computer image generation system where all that is being changed is the density of pixels along a raster scan line, an optimal distribution of pixel density about the point of gaze has not been fixed. A non-uniform distribution would conserve bandwidth in the sense that it would allow more resolution where it can be used by the eye, but the nature of its decline about the center of gaze depends upon a number of factors. Clearly as the center of this area must respond to eye and head position, the accuracy with which this can be done will determine how large the insert must be. The cost of display equipment will determine the bandwidth that the system can allocate over that area, and this will determine the resolution of the image for a given system. Hopefully knowledge about the information processing of human observers can place some restraints on how bandwidth should be spread about the visual axis.

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DR. STARK: I think you will find that saccadic suppression of image displacement will help you a lot more than just plain saccadic suppression of detection, which is what Volkman was plotting. As long as you project an image, even if it isn't in the correct position, the eye won't detect that incorrectness of position as easily as it will detect the absence or the presence of the image.

DR. CHISUM: You are suggesting that saccadic suppression using the saccade to suppress the projection will improve the perception?

DR. STARK: Yes, that it might work better than the data that was plotted would suggest.

RETINAL DISPARITY: DETECTION AND PROCESSING

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ABSTRACT

Retinal disparity is the cue to stereoscopic depth perception. Single neurons in visual cortex respond selectively to various kinds of disparity; the analysis of the visual scene for depth content doubtless begins here. Recent advances in our understanding of the detection process are reviewed. Beyond detection, the problems of a) globality and b) the plasticity of retinal correspondence await advances in our understanding of how disparity information is processed.

The story of disparity detection and processing is a tale of fact and fiction: we understand a great deal about the cortical basis of disparity detection, but subsequent processing remains a matter of conjecture. Obviously areas of conjecture are the fields of future research. My purpose here is to review recent advances in disparity detection in order to suggest problems which now seem ripe for investigation.

To start at the beginning, **retinal disparity** is the term given to small paralax "errors" or mismatches between the two retinal images. The mismatch is proportional to depth differences among visual field objects, and this gives retinal disparity its importance: disparity is the stimulus cue for stereoscopic depth perception, and, in fact, one of the visual systems's best sources of depth information. Super-position, for example, implies one object is in front of another, but does not tell us by how much. The straightforward geometric nature of disparity is illustrated in Figure 1. If two views ("half-images") are presented to left and right eyes respectively (Figure 1A) with some positional difference between stimulus elements (i.e., the different circle-triangle spacing, Figure 1B), then the elements will be perceived with an apparent displacement from each other in three-dimensional space. We have counterfeited the disparities in the two retinal images which real, displaced objects would generate (Figure 1D). This exercise reminds us that disparate stimulus positions in the two eyes' images are reconciled in the interests of single vision (Figure 1C). This small illusory, sideways shift in perceived visual direction is termed **sensory fusion.** To the extent fusion occurs, perceived visual direction is plastic rather than fixedly tied to physical stimulus location. Second, we are reminded that stereoscopic depth

is a cue-and-response system for the perception of the relative depth of objects, not their absolute distance from the observer.

DETECTION

A cell in the visual system which responds only when a particular stimulus is present may serve as a **detector** for that stimulus. Clearly the detector concept is bound up with the requirement of great **stimulus selectivity** among visual cells. Would the visual system be clever enough to develop cells not only responsive to the presence of depth, but selective for particular disparity values? Such cells exist, and the story of their discovery is bound up with parallel developments in human psychophysics. The discovery by Bela Julesz (1960) of the random-dot stereogram[1] showed that the visual system could produce vivid stereoscopic depth from a meaningless grainy texture. This texture pattern was devoid of extended contours and the familiar objects one might portray with them, as in a line drawing. Stereopsis seemed suddenly much simpler; the visual system did not necessarily elaborate full-blown percepts for each of the two eyes' images, recognize corresponding details in each, and then perform numerous exercises in plane geometry in order to extract hidden disparities. With random-dot stereograms, it seemed at first blush that disparity might be sensed directly by comparison of individual points in one eye's half-image with points in the other. The significance of point-by-point comparison, as we shall see, is that the receptive fields of cortical units are admirably suited to perform the task. Many neural scientists in the vision community were aware of these demonstrations, particularly after an interdisciplinary meeting in California (Nye, 1965), setting the stage for the discovery of a neural basis for retinal disparity detection (Pettigrew, 1965; Pettigrew, Nikara and Bishop, 1967, 1968; Barlow, Blakemore and Pettigrew, 1967).

Position Disparity Detection. Where excitatory inputs from the two eyes first come together, the visual system has its first opportunity to directly compare the eyes' two retinal images. It turns out that the visual system begins the search for retinal disparity information at the earliest available opportunity. A schematic experiment which demonstrates this is shown in Figure 2. With an electrode inserted in a single cell of the primary visual cortex, responses are recorded while stimuli are presented to the two eyes. The portion of the visual field where presentation of a stimulus elicits a change in responsiveness of a cell (here, an excitatory change) is termed the cell's **receptive field.** The receptive fields are schematized here as rectangles; an actual map is shown below. The point to note is that responses are not vigorous until the stimulus is aligned with the receptive fields of both eyes. The cell demands a particular triangulation of the stimuli, or, if you will, a particular depth with respect to the fixation point which the immobilized animal has here assumed. Again note that the triangulation does not give absolute distance. Depth is relative to the fixation assumed at the moment. And if the object whose depth we are detecting lies well into the periphery from the point of fixation, it is a moot point how we compare the depth of the two. To know whether the object of regard possesses any depth with respect to the fixation point, we must be able to specify the **horopter**, or zero-disparity reference plane, shown schematically in this figure as a curved surface. The horopter hides a host of problems of its own (Nelson, 1977). But let us say more of the progress that has been made before mentioning remaining problems.

[1]It has been pointed out (Shipley, 1971) that Aschenbrenner (1954) produced but never exploited the implications of a random-texture stereogram.

The selectivity of single cells for minute retinal disparities is exquisite, even in the cortex of the cat, whose stereoacuity is perhaps 1/12th that of man (Blake and Hirsch, 1975). The variation of response with disparity is described by a cell's disparity **tuning curve.** A disparity tuning curve is shown in Figure 3 (Nelson, Kato and Bishop, 1977). Contrary to the schematic experiment shown in Figure 2, left and right eyes of the cat were stimulated with entirely separate stimuli. The cortical cell was of course binocular, possessing receptive fields for both left and right eyes. The left eye receptive field was given an unchanging, optimal stimulus while the stimulus to the right eye was varied in position disparity. With disparity variation, the right eye stimulus marched onto and off of the receptive field, and so the response varied as shown. With separate stimulation, the contribution of the eyes could be evaluated singularly and in combination. Two incidental observations are noteworthy. First, the response to simultaneous (binocular) left and right eye stimulation (peak C, Figure 3) is greater than the mere algebraic sum of optimal responses to left and right eyes stimulated alone (monocularly). Second, in addition to this **facilitation,** there is an **inhibition** of response (maximum at A and E, Figure 3) to the completely optimal left eye stimulus when the right eye stimulus assumes an incorrect disparity value. These peaks and troughs of the disparity tuning curve can be related to the prominent features of a typical receptive field, as I shall show below. The main observation for now, however, is that the tuning curve is extremely sharp, and this selectivity is due to facilitatory and inhibitory interactions as the responses traveling inwards from the two eyes converge upon the one cortical cell under observation.

The disparity tuning curve is a functional property of single cells in visual cortex. It is an important property if one wishes to answer questions such as "How do we see depth?" or "Where does the brain begin the analysis of visual input for disparity content?" Two facts tell us the analysis begins in the primary cortical/projection area of the visual system, namely 1) the existence of tuning curves like the one we have examined, and 2) the fact that among many cells, tuning curves will be found with peaks at a variety of disparity values. The brain's disparity detection system is thus equipped to cover a range of disparity values, and to pinpoint an exact disparity value within that range. As a psychologist or psychophysicist, I will ask how the visual system uses disparity information for depth perception, but as biologists we might ask how the cortex does it. The disparity tuning curve is related to receptive field structure, and from receptive field structure we can infer the contributions from visual centers peripheral to cortex, and we can seek the subsequent modifications imposed upon those inputs by cortical processes. The map of a typical receptive field for a cortical cell of the sort which might have produced the tuning curve in Figure 3 is shown in Figure 4. The map covers an area of the visual field approximately 10 deg square; for a cat viewing a projection screen 2 m distant, this would be a patch 35 cm square. Small stimuli presented in the black regions will inhibit the cell; intense excitation occurs for stimuli presented in the central region which the inhibitory areas flank on either side. In a binocular unit, the receptive field one could map in response to stimulation of the same cell via the other eye would be very similar. Simultaneous stimulation of both excitatory regions by a properly triangulated stimulus (recall Figure 2) causes the disparity tuning curve's peak; the broad inhibitory regions suppress response to a variety of incorrect disparity values. The origin of the inhibitory regions themselves can be partly revealed by pharmacological manipulations of local synaptic function in cortex (Sillito, 1975; Tsumoto, Eckart and Creutzfeldt, 1979), and must utimately be linked cellular structure and projections.

Orientation Disparity Detection. Only position disparities have been dealt with so far, and, as Figure 1 shows, these arise when an object is displaced in three dimensional space from the point of fixation, either towards or away from the observer. If an extended object is tilted

in depth, say top away from and bottom towards the observer, orientation as well as position disparities arise. This is easily demonstrated with a pencil held in the position described. The view from the left side would be of a counterclockwise-rotated pencil, and the left eye's view, while not completely around to the side, nevertheless acquires a bit of this counterclockwise orientation. The orientation for the right eye is clockwise, and thus the visual system must deal with a disparity in the orientations of the two retinal images. Surfaces tilted in depth are as common in everyday life as the floor we walk on, and of course every tilted surface can generate both position disparities between various points discernable upon it, and orientation disparities between linear markings. Cortical cells are sensitive to binocular disparities of both kinds. The question of which cue the cortex uses in tilt detection is an interesting one, because it represents the limit today of the sort of functional question one can answer by direct electrophysiological investigation of cortical function. Working with Drs. P. O. Bishop and H. Kato in Australia, I have attempted to answer this question for the cat's visual system (Nelson, et al., 1977).

To compare position and orientation disparity discrimination by the one cell, we varied both cues simultaneously. While this required the presentation of 368 combinations of binocular stimuli over a period of several hours, it also made it possible to extract from our results the variation in response with orientation disparity when positional alignment was optimal for the cell, as well as the positional disparity tuning curve obtained with optimal stimulus orientation. The upshot of this was that for position disparity we observed the extremely selective tuning curves to which we are accustomed, whereas the orientation disparity tuning curve was broad. To make a more quantitative statement, some hypothetical stimulus situation must be specified. We chose a situation typical for the behaving cat (a line on the floor extending away from the point of fixation, viewed by a standing animal) and a stimulus length comparable to the dimensions of the receptive field which might analyze it (2.56 deg long). This line tilted in depth generates both an orientation disparity and position disparities, the latter maximum at the end-points of the line. We are now in a position to say what response either of these disparities would actually produce in a cortical neuron. The answer for one extensively measured cell is a 19 pct change in response for the orientation disparity of this stimulus, but at least a 37 pct change for the position disparity associated with the same stimulus. The results would be comparable for other cells we have measured. So it is possible to draw some conclusions about disparity detection for tilt perception: as a stimulus is tilted, the rising position disparities conveyed by points on the surface will produce a threshold-level change in the responses of cortical units before orientation disparities conveyed by lines on the same surface can do so. By a perhaps unwarranted extrapolation to man, one might predict that sensitivity to small changes in the tilt of a test surface would be more easily detected if the surface were "grainy" or textured, rather than striped. In any event, it is significant that the inference we may make from neurophysiological data such as these are all inferences about threshold behavior: the detection that a stimulus property (displacement or tilt in depth) is present or not, or has changed by a just-noticeable amount.

Other Detectors. The detectors we have been considering are tuned to a specific depth. Several years ago, Whitman Richards noticed that some students in his lectures were unable to perceive Julesz random-dot stereograms in depth, and was led ultimately to evidence for a rather different sort of disparity detector. Subsequent investigation with rather large disparity values revealed subjects for whom a certain broad class of disparities all appeared the same; forced to categorize such a stimulus as in front of, on, or behind the plane of fixation, such subjects performed at a chance level of success and confused the stimuli with monocular

"catch" trials (Richards, 1971). Differences have also emerged in an otherwise normal observer's ability to detect motion in depth, depending on whether that motion is beyond the fixation plane (and back) or from the fixation plane to nearer space (and back; Richards and Regan, 1973). These results imply that all the detectors for disparities signaling a stimulus nearer than the fixation plane **(crossed disparities)** behave as a group, behave differently from detectors for uncrossed disparities, and can be defective in certain individuals. One could get such behavior most parsimoniously if the substrate for binocular vision consisted of only two or three classes of disparity detector (crossed, zero, and uncrossed), just as the receptor substrate for color vision is based on red-, green- and blue-sensitive cones. This is a very different picture of the visual system from the classic neurophysiological one of a range of detectors, each tuned to a very specific disparity.

It is likely that visual systems are supplied with a greater variety of disparity detectors than we at first realized. (Poggio and Fischer, 1977) have been able to demonstrate in monkeys, cells which respond to a very large range of disparities for objects nearer than the fixation plane, and only to such disparities. They termed these cells "near neurons"; "far neurons" were also found. A fresh examination of the cat (von der Heydt, Adorjani, Hänny and Baumgartner, 1978) revealed, if not near and far neurons, at least units with asymmetrical tuning curves showing inhibition over a broad range of disparities, just as one might have expected (with hindsight!) from receptive fields with inhibitory regions lying asymmetrically to one side of the excitatory center. So there are certainly neurons which respond to all crossed disparities and other neurons for uncrossed disparities, and therefore a reason why psychophysically we might expect all near stimuli to behave differently from all uncrossed-disparity stimuli. The classic substrate of narrowly-tuned detectors (which monkeys also possess) is more refined than this. It yields quantitative depth information, rather than categorical "nearer than, farther than" judgments. In monkey and man, the brain may be prepared to provide such keen disparity detection services only for a limited range of depths. These are the depth intervals which surround our hands as we manipulate tools. Outside this range, "nearer than, farther than" is good enough, and certainly more economical.

In summarizing this discussion of disparity detection, it is clear that the classes of detectors with which the visual system is furnished determine the kinds of stimulus information available to the system, or likely to be missing in anomalous observers. This area of research is already able to answer certain psychophysical questions by appeal to direct neurophysiological study of the brain, although of course answers are never final due to differences between man and experimental animals. However, the questions with which we can now deal are only the simplest sort of threshold detection questions, and it is likely that we have not yet met all the detectors. How already known detectors achieve their performance remains a problem for cellular neurobiology.

PROCESSING

Once disparity is detected, we may ask how it is processed. It might be a long road from knowing the geometrical disparity of the stimulus to generating the final depth percept. We know, for example, that the visual system takes non-disparity cues like superposition and relative size into account when depth judgments are made. Even when the disparity cue itself is to be evaluated, the visual system must seek distance information and combine it with disparity information. This is necessary, because an object at different distances will generate different amounts of disparity; thus, a given amount of disparity should be worth more depth

if the object is handicapped by being distant from the observer (Wallach and Zuckerman, 1963). How disparity information is combined with information from other cue systems lies well beyond the current frontier of neurophysiology. I wish to consider two problems which lie immediately ahead and entirely within the confines of the disparity research area. These are the problems of globality, and of defining zero disparity.

Processing for Globality. Random-dot stereograms present certain ambiguities which disparity detection mechanisms must surmount. When a random-dot stereogram is constructed, the checkerboard elements or pixels of one half-image are made black or white at random. The second half-image is a duplicate of the first, save for a lateral displacement of a portion of the pixels (Figure 5). That displacement is the retinal disparity built into the pattern. The problem facing binocular cortical neurons of the sort we have been considering is the identical nature or uniformity of the pixels. True, a unit tuned to the lateral displacement will have its receptive fields aligned with two matching pixels (white in both eyes, or both black). But unfortunately, units with an assortment of other tunings will, at random, find matches as well. The way out of this **matching noise** problem lies in capitalizing upon the fact that only detectors of the correct disparity value will find more than random stimulation; units so tuned will be active at all points across the displaced depth surface. A neuron which finds its activity level in agreement with its neighbors of similar disparity tuning is probably being stimulated by the correct disparity value. **Globality** is the term given the undiscovered cooperative mechanisms which the visual system must possess to resolve the matching noise problem.

Globality would be achieved if active neurons of similar tuning could reinforce each other's activity, and suppress the activity in weakly or randomly-active neurons of other disparity tunings. This leads straightforwardly to the suggestion that disparity detectors of similar tuning must be mutually facilitatory even though their receptive field pairs might lie scattered across the visual field, while detectors of differing tunings, particularly units attempting to encode the disparity present in one visual field region, must be mutually inhibitory. I have developed such a model qualitatively and attempted to show that it accounts for a variety of other phenomena in stereoscopic depth perception (Nelson, 1975); others have offered elegant computer models along similar lines (Dev, 1975; Marr and Poggio, 1976). Note that the postulated interactions are intracortical. This inhibition and facilitation occurs among disparity detectors, each with their binocular pair of receptive fields displaying inhibitory and excitatory areas, and each with facilitatory and inhibitory interactions occurring in the confluence of input from the two eyes upon the one cell. The intracortical interaction model of globality is a good problem for the cortical neurophysiology of the 1980s. The work can begin with a relatively well-understood substrate where neurons acting as single units perform the initial detection, yet it clearly must take us beyond single-unit detectors to an understanding of the processing performed by **populations** of interacting neurons. The random-dot stereogram today continues to hold an ambiguous position in binocular vision, illustrating both the simplest and most complex aspects of disparity detection.

Processing for Zero Disparity. What is zero disparity? This is a subtle problem, and subtle problems often prove to be pervasive and fundamental. If one wishes to discuss how the visual system encodes the amount of stimulus disparity present, the zero point from which one counts up the disparity must be specified. I will consider an operational approach and an anatomical approach to the problem.

It is easy to define zero disparity operationally as the disparity which produces zero perceived depth, but it proves troublesome to apply the definition. It goes without saying that we are restricted at once to controlled, laboratory environments where all non-disparity cues to perceived depth may be eliminated or controlled in order to isolate the function relating disparity input to depth output. Once this technical problem is solved, the more intriguing problems begin. The disparity-depth relationship is subject to **contrast**, so that a small disparity produces a bigger perceived depth interval when presented next to objects of opposite depth displacement. In a special case of contrast, a flat plane or line will appear tilted when presented against a tilted background (e.g., Pastore, 1964 or the example in Figure 6), so that we have perceived depth from identical stimuli with no physical or geometrical disparity whatever. The sensory coding error will still be observed if the context which induces the contrast distortion is viewed at one time and the test stimulus at another; this depth **after-effect** (e.g., Blakemore and Julesz, 1971) is presumably due to cortical adaptation.

Depth contrast complicates the disparity-depth relationship by giving us depth output without local disparity input. There are numerous complementary cases where disparity input is present, but depth fails to be perceived. I have termed all cases of this kind **depthless fusion.** There are many everyday and laboratory examples of depthless fusion. When we fixate, the eyes exhibit **involuntary saccades.** These saccades are uncoordinated between the eyes, and easily carry the retinal image of one eye **at least** 3 min arc (approximately ten times the stereoacuity threshold) away from the other image on 50 pct of all occasions (Fender and Julesz, 1967). While oculomotor tremor, drift and involuntary saccades introduce dynamic errors, **fixation disparity** commonly places a steady offset on one retinal image with respect to the other, classically thought to be less than half a degree (e.g., Ogle, Mussey and Prangen, 1949), but in actuality more than twice that amount in some cases (Stewart, 1951). In **asymmetric convergence** or with **anisometropia** where spectacle lenses of different powers are worn, the retinal images do not match in size.

In the laboratory we find subjects perceiving random-dot stereograms differing 7 deg in **orientation** from one another (Julesz, 1960), or failing to respond to disparities increased with a **telestereoscope** unless a scene is enriched with perspective cues (Wallach, Moore and Davidson, 1963). In the **induced effect** (Ogle, 1964, Chap. 15), vertical disparities (which alone never produce perceived depth) alter the disparity-depth relationship for any horizontal disparities present in the visual field.

Anatomy has always provided at least the hope of a definitive specification of zero disparity. We can indeed find in the fovea an overt mark in each of the two retinas. If it were not for oculomotor imperfections like fixation disparity, these landmarks would label two corresponding points, but no others. Classic binocular visual system investigators (Ogle, 1964), recognizing such shortcomings, hoped that centrally projecting anatomical pathways would still provide a zero-disparity specification. These investigators reasoned that paths from the two eyes must eventually join in the visual cortex. Once we can say that this left retinal point and that right retinal point where such a pathway originates are indeed joined in the cortex, we should be able to specify the two points are exactly corresponding and so of zero disparity. The anatomy was correct, and the feat once only imagined is now routinely performed with microelectrode recordings.

Modern neurophysiological advances leave us less able than ever to define zero disparity through an appeal to anatomical paths and projections. From the capsule review above of the

disparity detection process, it is evident that the cortex accommodates many possible states of correspondence. In order to be able to detect a usefully wide range of disparities, it is necessary to have a collection of units with a range of different disparity tunings. In this way, there will always be an appropriately-tuned detector capable of vigorously responding to any disparity stimulus which the animal is likely to encounter. What is to give one tuning and not another title to the zero disparity label? In going one step forward in understanding disparity detection, we have lost our foundation for understanding what makes points corresponding.

It seems inescapable that a century of research in binocular vision has failed to produce a hard and fast definition of corresponding points because corresponding points are constantly shifting. Neurophysiology tells us that a range of correspondences can be supported by the substrate, perhaps not all equally well, but a range nevertheless. Psychophysics shows us that the disparity-depth relationship is extremely labile. It may be time to replace the historical view of correspondence as something fixed with the view that correspondence is **plastic** in the normal adult observer (Nelson, 1977). Correspondence seems to shift in response to stimulation, often absorbing large disparities across the whole visual field. It is as if the visual system first recalibrates its zero point, seeks local departures in disparity from the new, field-wide zero, and assigns depth only to these. The magnitude of a local departure from zero depends on the state of the visual system at the moment as much as upon the physical stimulus which has been presented to it in one locale.

A more plastic view of correspondence may be had by developing a definition of corresponding points based on **activity** of the binocular visual system rather than primarily its passive **structure.** This model of correspondence is dynamic, where previous approaches have been static. Given a better model of correspondence, we would then want to know the mechanisms which govern moment-to-moment changes in the manifest state of correspondence. Until we make these advances, there are bound to be surprises with practical displays and psychophysical studies of three-dimensional depth perception.

CONCLUSION

We now understand the neurophysiological basis for detection of the disparity cue for perceived stereoscopic depth. It is possible to decide by direct electrophysiological recording of single-cell response whether one sort of disparity cue is detected with greater selectivity than another. Ultimately the functioning of detectors will be related downwards to receptive field structure, and to synaptic and biophysical processes. Looking upwards to higher perceptual processes, the processing of detected disparity information seems the next logical step in the neurophysiological study of binocular vision. However, the separation of detection and processing is not as clean as we might wish. For random-dot patterns, detection itself is impossible without global processing. In many situations, processing seems necessary to define correspondence. In all cases, the processing probably involves intra-cortical interactions among neurons with different disparity tunings and different visual field locations. In short, processing always involves relations among the parts of a stimulus. Disparity detection and processing may be so intertwined in binocular vision because depth, unlike absolute brightness, orientation, etc., is itself a **relational** percept, namely the relative separation in depth of at least two objects. However difficult, the effort expended in understanding these problems in binocular vision will be well rewarded, as many of the big questions lying ahead in sensory cortex and beyond are questions of processing.

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J. I. NELSON

DISCUSSION

DR. STARK: Do you distinguish in your neurophysiology between disparities for vergence control and disparities for stereopsis?

DR. NELSON: Oculomotor control has been swept under the rug by neurophysiological investigators today. They are all working with paralyzed preparations, not awake preparations. So, they have eliminated all eye movements within their experiments and possibly therefore in their thinking as well. Hopefully, when we move to behaving preparations we may gain valuable information about oculomotor control. If there is a distinction to be made, as you suggest, then I am sure that the first one to be tested will be the distinction between the Richards type categorical or range detectors and the Bishop type point disparity detectors. It may well be that the Richards range detectors may be used for oculomotor control to tell the oculomotor system you're off and in this direction. Once the servo system corrects, then the more finely tuned classic Bishop type detectors can provide relative depth information. I guess that's a long way of saying we don't know.

DR. WOLBARSHT: Well, wouldn't you expect the part of the visual system relating to eye movements to play a bigger role in the colliculus rather than the cortex?

DR. NELSON: It is certainly true that we have a motion-sensitive unit with large visual fields in colliculus, with preferred directions in motion, that would be quite appropriate to guide the eyes back to a central point. My feeling has been that the colliculus is probably more involved in gross head and neck orienting reflexes; that after that comes the Richards type zone detector and then finally the Bishop type detector for fine depth intervals around the hands. So, we have servo systems upon servo systems. But we always knew it was a good computer.

DR. GINSBURG: Frisby & Mayhew presented a paper where they did filter some stereograms and they argued that you would not get stereopsis if you had certain filtered images that had a band width greater than about one octave. What I did was then filter a couple of simple images and showed you could get stereopsis and you could get correct depth judgement with over two octaves between the two images. Do you have any feeling about the role that the band width of these cells that you are talking about plays in terms of stereopsis and concomitant depth?

DR. NELSON: It's a long line from the psychophysics of spatial frequency to current detectors. In general, I accept the results. There's nothing else to do. One can band width filter stereograms and convey different amounts- -different disparity values in one frequency zone and others in another and see two alternating depth percepts. My expectation, like anyone else's, would be that if one eye and the other eye see entirely different spatial frequency content, they ought not be able to put them together.

DR. GINSBURG: These were quite reliable results and they sort of tend to make one look at stereopsis not particularly in a point-by-point mechanistic way but rather in dealing with images.

DR. STARK: I don't think the superior colliculus has been involved in vergence eye movements or vergence detection.

DR. REINECKE: Could you comment on the inhibitory-excitatory relationship of the fovea or area centralis versus the peripheral units?

DR. NELSON: Clinically the central vision behaves very differently under conditions of strabismus and so forth than does the periphery. We had a lot of trouble finding binocular cells in central vision in the cat. While the project was going, Olvus in Germany came out with a paper showing quantatively that in the cat many of the central cells were monocularly excitable. A fact that other laboratories sometimes lose track of is that while the cell may be monocularly excitable it may very well have an inhibitory in-put from the other eye. In a survey of over a hundred units, Bishop, Kato and Orban were unable to find more than six cells which were monocular in every sense of the word, having neither excitatory nor inhibitory input. The stage is then set that the central area may achieve its binocularity chiefly through inhibition in one eye, although this is cat data and a monkey is another bag of tricks. That then gives us an inhibitory process which would knock out a large population of cells when disparity tuning is inappropriate.

In addition, of course, there is the X-Y story. The X-Y story in ganglion cells has implications for the simple complex dichotomy and cortex, and those cells have very different disparity properties. So, we have a lot of opportunity to explain the clinical data but we don't have the evidence for singling out which opportunity to pursue.

CONTINUOUS EVOKED RESPONSES AS AN INDICATOR OF "G" TOLERANCE

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Modern high performance jet aircraft are capable of generating and sustaining accelerative forces at magnitudes and for durations that far exceed the tolerance limits of their human operators. The primary effect of the accelerative forces is such that the downward (G_z) loading of blood in the heart-brain hemodynamic column exceeds the upward forces generated by the action of the heart. The net effect is that blood is pooled in the lower extremities and the abdomen, while the eyes and the brain are deprived of freshly oxygenated blood. In sequence, diminution of visual functioning, peripheral light loss, central light loss, blackout, and unconsciousness rapidly ensue.

The heart-brain hemodynamic column, a distance of approximately 280 mm (Burns, 1975), produces downward forces of approximately 280 gm in a 1.00 G_z environment. Because blood pressures are clinically described in terms of mm of Mercury (Hg), we will use that convention here. Since the density of blood is approximately .0735 (i.e., 1/13.6) that of Hg, the heart-brain column is roughly equivalent to a column of Hg that is 20.6 mm in height. Assuming the peak systolic pressure of blood at the level of the heart to be approximately 120 mm Hg (i.e., normal peak systolic pressure), the G environment at which bloodflow to the brain would cease in an unprotected and uncompensated subject is of the order of 120/20.6, or 5.8 G_z.

Intraocular presssures are of the order of 20 mm Hg. Thus, bloodflow to the retinae should cease at a level of approximately (120-20)/20.6, or 4.9 G_z, about 1 G less than the level at which the brain itself is deprived of its supply of oxygenated blood. Visual criteria for human G tolerance have often been adopted because the visual changes generally precede the loss of CNS functioning and unconsciousness.

The preceding discussion considers the effects of G_z accelerative forces on unprotected and uncompensated human subjects, and clearly, this description of human cardiovascular functioning in acceleration environments represents only a first order approximation; the situation is by far more complex than the discussion indicates (Betz, 1972; Krutz, Rositano, & Mancini 1975). Nevertheless, as a first order approximation of the effects of exposure to acceleration environments, the preceding discussion does provide sufficient information to allow us to examine some currently employed methods for enhancing human G tolerance.

Obviously, one method to enhance G tolerance would be to reduce the height of the cardiovascular column between the heart and the brain. This can be accomplished by tilting the subject backwards so that the downward G_z accelerative forces are replaced by G_x forces

directed from chest to spine. This technique allows an increase in G tolerance to more than 11 G on the airframe. Another technique to enhance G tolerance is to prevent pooling of blood in the lower extremities and the abdomen, thereby increasing the volume of circulating blood; this can be accomplished by inflating the bladders of a conventional g-suit. The g-suit provides between 1.5 and 2.0 G additional protection. Still another technique is to have the subject attempt to exhale against a closed or partially closed glottis, the L-1 and M-1 maneuvers, respectively. These maneuvers increase intrathoracic pressure, diminish blood pooling, and provide about 1.0 to 2.0 G additional protection.

Irrespective of the specific methods are employed to enhance G tolerance, it is extremely important to be able to evaluate the degree of G protection afforded by all methods. Determination of the tolerance limits for human subjects traditionally has relied on behavioral and subjective methods such as: 1) requiring subjects to indicate the apparent brightness of a series of lights, 2) requiring subjects to respond by terminating randomly timed presentations of lights in various parts of their visual fields, 3) requiring subjects to manipulate the positions of lights to provide a nearly continuous indication of the limits of their visual fields, and 4) observing ocular motility when lights are presented in various positions.

In addition to behavioral tests, objective indicators of bloodflow to the brain have been employed, and non-invasive techniques such as Doppler measures of bloodflow velocity have been quite promising (Rositano & Sandler, 1969). Although Doppler flow velocity measures can provide objective criteria for human G tolerance, their interpretation is sometimes extremely difficult, for they critically depend on the position of the sensors relative to the underlying arteries; both the sensors and the arteries can be displaced under acceleration, particularly when the subjects perform straining maneuvers such as the L-1 and M-1. Further, the Doppler techniques do not take advantage of the added margin of safety provided by intraocular pressures that terminate bloodflow to the retinae before bloodflow to the brain is impaired.

The behavioral measures of G tolerance, although they do take advantage of the extra safety margin afforded by intraocular pressures, are behaviorally invasive; i.e., when subjects perform on the visual tasks, they cannot simultaneously perform other, piloting-related, tasks. Further, the behavioral measures are frequently unstable, often providing tolerance limits that differ by more than 1 - 1.5 G from test to test. Thus, it would be desirable to obtain methods for evaluating G tolerance that have the following characteristics: 1) they should be reliable and reproducible, 2) they should be non-invasive both physically and behaviorally, 3) they should be objective, 4) they should be relatively insensitive to experimental artifacts, 5) they should be capable of rapid, online, real-time discrimination, and 6) they should afford a margin of safety for determining G tolerance without undue risk of approaching unconsciousness. Objective measures of the integrity of the visual system during retinal ischemia appear to have a potential for meeting these criteria.

Animal studies (Brown & Watanabe, 1965) have shown that general anoxia affects the more central parts of the visual pathways first, beginning with the cortex, and progressing to the lateral geniculate nucleus, to ganglion cells, to bipolar cells, and, finally, to the retinal receptors. However, during G_z acceleration, ischemia is manifested first in the retinae, where, as the local arterial pressure falls, the high intraocular pressures of the order of 20 mm Hg cause occlusion of the blood vessels beginning with the capillaries. The ischemia occurs first in the periphery of the retina because the caliber of the capillaries generally decreases towards the periphery (Ward, 1968). Thus, the loss of peripheral vision, progressing to loss of central vision and black-

out, may be attributed to retinal ischemia. These retinal events are considered to precursors of unconsciousness due to cerebral ischemia (Duane, 1954; Fraser, 1966; Leverett, Kirkland, Schermerhorn, & Newsom, 1966; Mercier & Duguet, 1947).

In 1962, Duane, Lewis, Weeks, and Toole demonstrated visually discriminable photic driving of the filtered EEG that followed the frequency of the stimulus. Although all subjects did not demonstrate the phenomena with the electrode placements, driving frequencies, and recording methods employed by these investigators, their results were encouraging. Subjects were exposed to accelerative forces in the human centrifuge while measures of peripheral light loss, photic driving of the EEG, and ophthalmoscopic observations of the retinal arterioles were obtained. Ophthalmoscopically observed collapse of the retinal arterioles was associated in time with both loss of photic driving on the EEG and peripheral light loss. Blackout coincided with systolic collapse of the arterioles. In this study, photic driving appeared to be lost approximately one second before the subject signalled grayout (dimming of the peripheral visual field).

Cohn (1969) reported that visual evoked responses recorded from scalp electrodes constitute a non-specific cortical response to light that does not necessarily stand in a fixed relationship to conduction along the classical anatomic visual pathways. This conclusion was drawn from experiments in which cortical and subcortical injury to the occipital lobes by crush or ablation was followed by an immediate decrease in the amplitude of the summated evoked cortical responses to light.

In addition to evoked responses at the cortical level, the ERG, consisting of a negative a-wave thought to be generated by the receptor cells of the retinae, and a positive b-wave considered to reflect activity in the bipolar layers of the retina (Ward, 1968), may provide an additional objective measure of retinal ischemia and G tolerance. The amplitude of the averaged ERG is greater than the averaged evoked cortical response by an order of magnitude (Tepas, Armington, and Kropfl, 1962). As the luminance of the stimulus is decreased, the ERG virtually disappears, while the summed occipital response remains. Thus, the ERG may provide a more sensitive index of retinal functioning than the cortical evoked response. If the sensitivities of the two measures to decreased stimulus intensity parallel their sensitivities to retinal ischemia, the ERG might very well provide an excellent indicator of G tolerance. In fact, (Ward, 1968) has observed that the amplitude of the ERG b-wave fell by 40% in anesthetized beagles when they were exposed to 1.5 G_z, and disappeared completely when the animals were exposed to 3.0 G_z. Unfortunately, equivalent research has not yet been conducted with human subjects, and the value of the ERG as an endpoint remains to be determined.

Recent advances in bio-electronics such as high-gain steady-state lock-in amplifiers, fast Fourier transform techniques, and improved real-time digital computer processing methods have combined to make feasible the continuous real time analysis of small amplitude bio-electrical signals that, in the past, could not have been recovered from background noise. Since, from a physiological perspective, changes in visual functioning should provide a reliable indicator of G tolerance (Coburn, 1970; Gillingham and Krutz, 1974), and since both evoked cortical responses (Donchin and Lindsley, 1969; Richards, 1977) and ERGs (Tepas, Armington, and Kropfl, 1962; Ward, 1968) have been shown to provide reliable indicators of visual functioning, it appears that time is now ripe to exploit these techniques in the determination of human tolerance to acceleration.

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MALCOLM M. COHEN

DISCUSSION

COL TREDICI: How do you get your signals? I guess you were doing this in humans in a centrifuge.

DR. COHEN: We were doing this initially in a dark room. Then we were doing it in a light room. We were getting set up to do it in the centrifuge. We had the subjects move about, however, and there did not appear to be too severe movement artifacts with this. We were able to get that fairly well under control.

COL TREDICI: How are you going to get this energy from inside the centrifuge back out? I always thought there were a lot of problems in the amplitudes that you are going to be dealing with in EEGs and ERGs to get - - you know, that error may be bigger than the whole thing.

DR. COHEN: Well, you are dealing with a signal on the order of maybe four microvolts or better when you evoke the response. We have high gain amplifiers, very low noise slip rings, and that is not envisioned to be a problem at all. I am worried about other things, particularly the tension variable and the degree to which the subject maintains his alertness. He's got to be in the situation without drifting off and losing vigilance in terms of what is expected of him here. We flash the light, and if his attention level is high, even though he's not fixating the particular test light, we will still get a response.

DR. CHISUM: By doing some amplification before you try to put the signal through the slip rings, we have been able to pick up ERGs off the centrifuge a long time ago. So that getting the signals out is not the major hurdle.

DR. WOLBARSHT: Well, I would suspect that VER as you are doing it might not be a good test because it's mostly a test of macular function, and your gray-out really starts at the periphery. What you want is a measure of loss of peripheral retinal function; is that correct?

DR. COHEN: There may be a component that is extra-macular.

DR. WOLBARSHT: Let me make a suggestion how to get around your problems, and that is to use the electrical visual evoked response, which you can do with about the same electrodes as you pick up eye movements. You will get stimulation of the peripheral retina preferentially that way, and you will be able to pick it up.

DR. GERATHEWOHL: You are aware, of course, what O'Donnell is doing in Wright Field with evoked potentials. He may have the answer to your problems because he can use frequencies, even on the instrument panel, for instance, on CRT panels the pilot's attention is directed to the type of information he has to get.

DR. COHEN: Recording how and where?

DR. GERATHEWOHL: Recording evoked potentials from the brain just through normal electrodes built in the helmet.

DEPENDENCE OF FOVEAL VISUAL ACUITY ON THE SIZE OF THE RECEPTIVE FIELDS OF RETINAL GANGLIONS CELLS

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The experiments described in this report are designed to discover some of the cellular bases of spatial vision. The approach taken is to find and describe the factors limiting spatial vision. The clearest limit to spatial vision is on the resolution of fine detail (acuity) and the experiments discussed are mostly designed to investigate this limit.[1]

The first limit on a visual task is imposed by the optics of the eye. For spatial resolution a complete description of an optical system is provided by its modulation (spatial frequency) transfer function (MTF). In the case of the eye the MTF is known and sets an absolute limit to resolution, a limit human acuity comes remarkably close to achieving.[2]

After the optically degraded image is formed on the retina, two new limiting factors come into play. The first is the transducer elements, the receptors. They are usually considered to impose a limit by their size and spacing. The second factor is neural processing which is limiting by the size of the area of summation, any lateral interaction, and any reduction in the number of output channels as compared to the number of receptors. Much less is really known about the transfer function of each of these factors than about the transfer function of the optics. This is partly because it is very difficult to obtain quantitative information from the electrical recordings from the receptors. This leaves as the only general approach to record ganglion cell activity and to deduce what has happened in the earlier stages.

A view which is commonly held has acuity limited only by the receptor shape and spacing.[3] Indeed, most investigators have concluded that the receptor spacing imposes the absolute limit. If the very reasonable assumption is made that the receptor responds to light in the same way no matter what the distribution of this light on the receptor is, then changes in light within regions less than the size of the receptor cannot be signaled. A further development of this theory considers the receptors as sample points for which the spacing limits frequency reception in accord with the Shannon-Nyquist sampling theory.[3] The Nyquist sampling limit for this case would be a spatial sampling (rather than temporal) rate which must be at least twice the bandwidth of the input of resolution of the signal.

There is a rough agreement, at least, of the limits of visual resolution for high spatial frequency (with the optics removed) to twice the receptor spacing. This could be a coincidence since two factors are not explained. The first is that the Nyquist sampling limit refers to point

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samples, although the receptors are not points but rather cover most of the available space. Perhaps this causes a certain reduction in resolution when the signal-to-noise ratio is very high, but this local integration is very important in improving the signal-to-noise ratio for lower contrast stimuli. The second point is that the receptors form a two-dimensional sampling array while stimuli which achieve the Nyquist limit frequency vary in only one dimension. Thus, in theory, many samples are taken for any position. When considerations of noise (both noise in light due to local scattering general scattering, and quantal fluctuations, and noise in the receptor itself) are added to the two previous points, the situation is very far from one in which sampling theory can be applied.

The remaining portion of the visual system which can limit resolution is the integrative, neural network of the retina, and few workers have examined this locale.[4] The **prima facie** case is that the neural integration of relatively large areas into a ganglion cell receptive field is similar to the earlier, more local, spatial integration which occurs at the receptor level. Since a spot of light in one part of the receptive field can be adjusted in intensity to produce the same response as a spot in another part it seems that spatial information is being lost. However, this is not necessarily true. The difference between these two spots is lost only for that particular ganglion cell. Other ganglion cell receptive fields overlay this same area and a correlation between the responses may allow the two spots to be distinguished. However, a different organization with non-overlapping receptive fields is usually postulated for the primate fovea.

Most anatomists consider that the fovea in the primate has a unique midget ganglion cell connection to each cone through a single bipolar cell. If this is true, then the neural organization is simply a point to point relay system and contributes nothing to acuity. However, there is no physiological evidence for a single cone representation in the cortex. In fact, the limited available data on foveal receptive fields (Westheimer's[5] psychophysical test of the effects of background size, and DeMonsterio's[6] rhesus fovea recordings of 15-23 μm fields) suggest (weakly) that the foveal receptive fields are composed of at least a few cones. There is also a growing body of anatomical data that the neural organization is quite complex and not equivalent to a simple relay network.

ELECTROPHYSIOLOGICAL DATA AND EXPERIMENTS

The first decision in an electrophysiology investigation is the choice of the experimental animal. There are two obvious candidates in tests of spatial vision: the monkey because of its supposed similarity to humans and the cat because there is already a large body of experimental data on this animal. The best choice is to do enough work on each to bridge the gap between psychophysics and physiology.

The ganglion cells of the retina have been selected since these are the most peripheral cells which can be routinely monitored long enough to complete the experiments. The experiments and their interpretations can be grouped as follows:

1. It is well known that acuity falls with increasing eccentricity from the optical center of the retina. This has often been used to support both the theory of a receptor limit to acuity,[7] and the theory of receptive field limits[8] since the receptors and the receptive fields both increase in size with eccentricity.

A comparison between visual acuity and the recordings of receptive field properties (especially the size of the central portion) from ganglion cells of known eccentricity (and known cone density) will distinguish between these two theories. A number of recordings will be necessary since some variation of receptive field size at one eccentricity does occur.

2. The increase in acuity with increase in luminance is also well established. However, its explanation is not. The limit imposed by receptor spacing might explain an increased acuity with increased luminance by the improvement in the signal to noise ratio. This ratio should vary with the luminance, at least where the receptive fields are large. Those theories that limit acuity by receptive field size make the assumption that the receptive field sizes are not fixed but decrease with increasing luminance.[9] This analysis provides a testable prediction of the receptive field theory. If the fields do not change size with luminance, a receptive field influence on acuity is still possible, but the transform between the contrast sensitivity function in the spatial frequency domain and the shape of the receptive field sensitivity profiles would be shown to be unreliable and falsely predictive.[10]

3. The Shannon-Nyquist sampling theory states that the resolution of a system is based on its sampling rate. To apply this theory to the retina raises question of what process in the retina should be considered the sampling rate. For a pattern which varies in only one dimension, such as the standard grid pattern, the effective sampling frequency could be increased by a combination of many rows of receptors. However, occurrence of this sort of integration and its dimensions, if any, the effect of width (orthogonal to the direction of pattern variation) upon the contrast sensitivity of a cell can be measured experimentally.

4. The simplest test of the receptor limit theory would be a measurement of the performance of the system after part of the receptors are eliminated. If receptor density is limiting this would reduce acuity proportionally. In both cats and diurnal primates the available evidence indicates that visual acuity is determined by the red and green cone inputs pooled without distinguishing the spectral differences. As the number of red and green cones are approximately equal, a measure of the acuity of the red cones (or green cones) alone can be accomplished by adapting an area with strong green (or red) light then using red (or green) test stimuli. This will show the acuity of the retina with half the normal receptor density with a predictable decrease from the normal visual acuity if receptor density is the limiting factor. This would not work if the pooling occurs before the adaption. Unfortunately Stiles' μ-5 mechanism suggests that just such a type of pooling really occurs.[11]

Another method to accomplish a reduced cone density is to put a stabilized laser speckle pattern of adaptation on an area and compare the reduced acuity this produces with the reduced acuity due to a uniform field. The difference between these two adapting situations should affect only the receptors since the adaptation effects on the ganglion cell would be the same. This again allows a comparison between a normal and a reduced cone density population. A non-stablized laser pattern should have the opposite effect. The receptors would see a constant average intensity and the ganglion cell responses would change.

5. Scotopic acuity is very much lower than photopic acuity. This is generally attributed to the large integration areas of scotopic vision. However, there is little or no break between scotopic and photopic regions in acuity versus luminance plot, and low scotopic acuity could simply be a function of low luminance. If this latter explanation is correct then the scotopic acuity should continue to increase smoothly with luminance through mesopic light levels. To

measure this acuity cone intervention must be postponed to higher luminance levels. This can be done in several ways: with a displaced pupil (Stiles-Crawford effect) to favor the rods or a red background adapting light with a large blue test pattern.

6. Whichever system imposes the limiting point for acuity, a problem still remains in the primate retina outside (and possibly within) the fovea for the coding at the ganglion cell level of all the information received by the more numerous receptors. For example, overall there are about 10^8 receptors signaling through 10^6 ganglion cells. Even the estimates for primate fovea place the ganglion cell/receptor ratio at about 0.9,[12] but all the ganglion cells in this population may not contribute equally to acuity vision. However, there may be overlapping and somewhat independent systems for both ON and OFF center. Outside of the fovea there are as well X, Y, and W cells. Certainly any W cells which project only to the superior colliculus must be subtracted from the ganglion cell population in acuity considerations.

ELECTROPHYSIOLOGICAL MEASUREMENTS OF GANGLION CELL RECEPTIVE FIELD PARAMETERS RELEVANT TO VISUAL ACUITY

Our experimental program has been devised to test certain models of ganglion cell coding. This required an analysis and an appreciation of the realistic parameters of ganglion cell receptive fields.

The most important information is the ganglion cell receptive field sensitivity profile. Two methods have been generally used to measure this sensitivity profile (a small exploring spot, and progressively larger spots) but there are problems with both. The first method uses a small exploratory spot, but has the drawback that a spot of light small enough to provide the desired resolution still has an appreciable optical spread. To make matters worse white light is often (even usually) selected for the stimulus.

In the cat (by far the most tested animal) the optical spread from a point of white light imaged on the retina has a diameter to 1/e intensity of almost 10' of arc.[13] Even if a ganglion cell's sensitivity profile were a single receptor, an experimenter exploring with a 6" test spot (perhaps the limit of the test stimulus itself for most tangent screen optical stimulators) would find a receptive field of at least 15" to the 1/e full in sensitivity of the test stimulus itself. This is shown in Figure 1. It is interesting that this size is the smallest reported for cat ganglion cells to date.[14] More accurate measurements of field size can be made for larger receptive fields, but the 15" integration (optical spread plus physical spot size) smooths the fine details of any sensitivity profile. The Gaussian-shaped sensitivity profiles generally reported could in fact be produced by a great variety of actual sensitivity profiles if the stimulus had a 15" Gaussian-shaped intensity profile as illustrated in Figure 2.

VARIATION IN RECEPTOR OUTPUT AS A FUNCTION OF LUMINANCE

Inaccuracies in plotting ganglion cell receptive fields may arise from the case where receptor output equals a constant times log luminance. If all other stages are linear and the sensitivity of the particular group of receptors A is twice the sensitivity of the different group B then the receptor response at summation point (the input to the ganglion cell) from A and B will be equal when B receives 10 times the illumination of A. This is shown in detail in Table I. Either

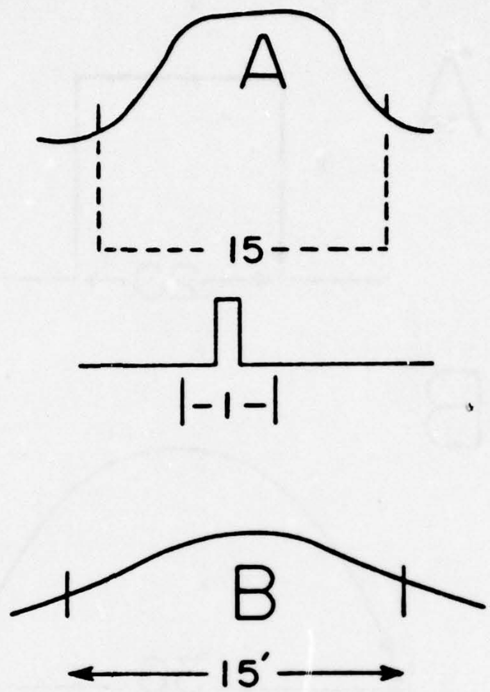

FIGURE 1

Receptive Field of a Single Receptor as Mapped with a Point Spread Function

Optical spread of 6' spot on the cat retina convolved with a 1' sensitive field due to one receptor. The response gives the optical spread of the 6' spot. Since the receptor diameter is very small compared to the optical spread the response acts like a Dirac function.

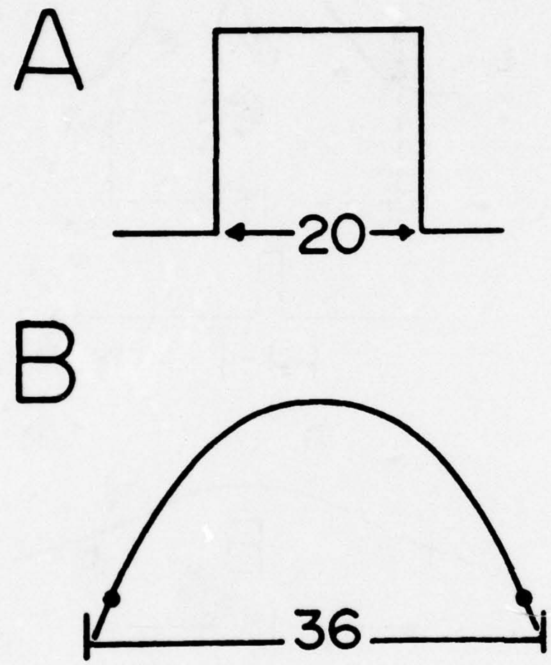

FIGURE 2

Distortion of a ganglion cell sensitivity profile when tested with a Gaussian point spread function stimulus. The true sensitivity profile (A) is convolved with a Gaussian point spread function to give the measured sensitivity profile (B).

TABLE I

Variation in Receptor Output as a Function of the Luminance

Receptor Group A		Receptor Group B
0		0
Sensitivity = 1		Sensitivity = 1/2
Stimulus 10 Units of Light		100 Units of Light
Response at Summing		R = k/2 log (luminance)
Point = K log (luminance)		
R = K log (100)		R = k/2 log (100)
R = K	=	R = k/2 · 2 = K

Inaccuracies in plotting ganglion cell receptive fields may arise from the case where receptor output equals a constant times the log of the luminance. If all other stages are linear, and the sensitivity of a particular group of receptors (A), is twice the sensitivity of a different group (B), then the receptor responses at the summation point (the input to the ganglion cell) from A and B will be equal when B receives 10 times the illumination A.

method can produce a more accurate estimate of the sensitivity profile if appropriately modified. The use of a small exploratory spot with the experimentally obtained sensitivity profile is needed to arrive at the true sensitivity profile.

A Ricco plot method produces an accurate sensitivity profile regardless of non-linearities of the stimulus intensity-response function as long as this function has the same constitution in all parts of the field. If the field is not homogeneous, a correction can be made by the following procedure. A measurement of the response (in number of spikes) with different spot sizes (centered spots of an increasing diameter) for a fixed intensity, followed by measurements of the response (in spike numbers, again) as a function of intensity for a fixed spot size, a Ricco plot (intensity vs. spot size for a constant response) is obtained with the points which produce equal number of spikes (Figure 3). The cell sensitivity profile can be derived from this.

The experimental work described above has its main value in the limitations it places on acuity by the receptor size, the ganglion cell receptive field organization, and by modification to the various models of visual acuity. As pointed out earlier the receptors are two dimensional arrays of extended (as opposed to point) detectors. Strict sampling theory does not necessarily apply to extended sampling processes, but some numerical methods can closely mimic the actual receptor sampling. The receptor may be considered as integrating light over a certain area with an output (response) which is a function of the integral. When a receptor array is set up, its response to an acuity target must be convoluted with a transform function which represents the actual intensity variation on the retinal receptors. This, then, will give the maximum theoretical acuity as a function of the receptor density. Receptor outputs can then be combined with a weighted summation to produce the theoretical ganglion cell output. A particular attempt will be made to find the area of summation and the weighing function which preserves as much information as possible from the receptors. However, in any case where there are more receptors than ganglion cells, the weighting function and the area of summation will have their boundary conditions imposed by the data from the electrophysiological experiments.

Another important characteristic of the retinal ganglion cell receptive field is the center-surround antagonism. In certain respects the effect of the surround antagonism on the center is similar to the well known lateral inhibition in the Limulus eye although the neural mechanism is quite different. Also, as in the Limulus, under some conditions the spatial properties of the surround antagonism could contribute to the production of Mach bands. This surround antagonism might be the basis for the lumped nature of the sensitivity versus spatial frequency curve (Figure 4). The spatial frequency peak might be determined by the stimulus width which matches the receptive field center and reverses polarity at the same place that the cell's sensitivity profile reverses polarity. This surround influence might also explain the changes in the spatial frequency, CSF, and luminance. If the peak of the CSF is indeed due to the surround antagonism, then the surround can be supposed to diminish with luminance fall. Since the CSF curve flattens with fall in luminance, it is known that at very low luminances the surround effects do vanish. This might be the extreme luminance effect on the surround strength. If changes in overall luminance level produce a different surround effectiveness, then spot stimulation of the receptive field will not clearly demonstrate receptive field changes with the luminance (Figure 5). A bar stimulus, however, with a large integrated area in the surround field would give an easily detectable change in the response function with changes in the luminance level.

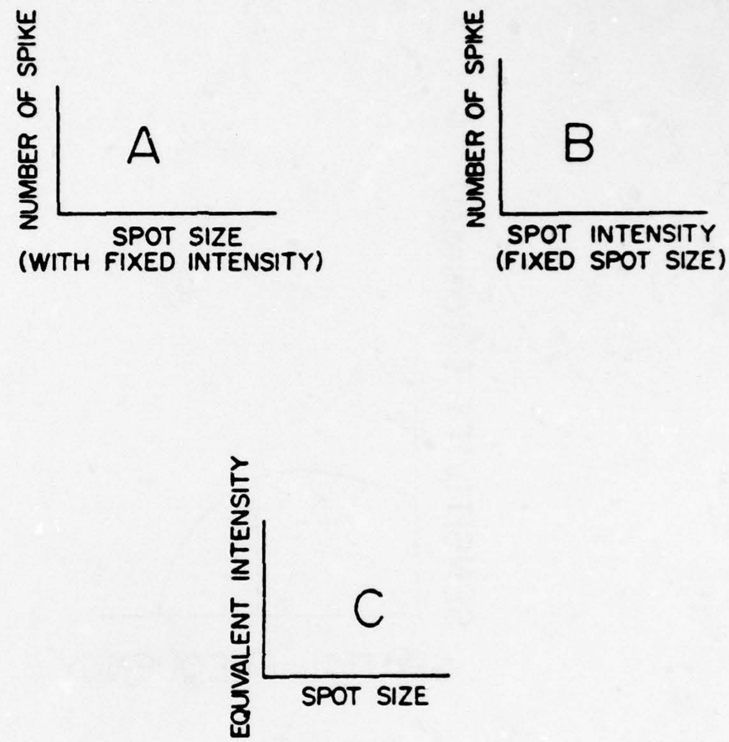

FIGURE 3

Response from Ricco Field Plot (Area vs. Intensity)

Graph C takes as equal those stimuli which produce equal responses from Graphs A and B. This approach assumes only that equal output implies equal input. It assumes nothing else about the nature of the response - stimulus relation.

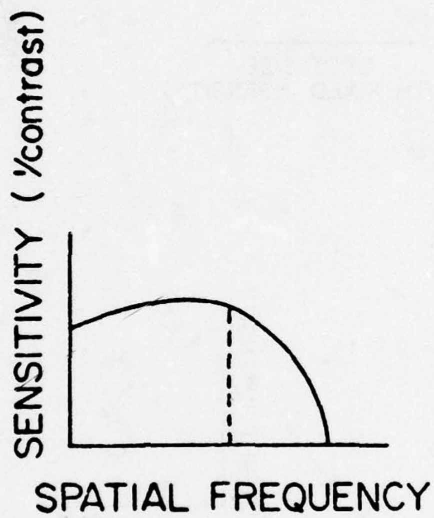

FIGURE 4

Spatial Frequency as a Function of Sensitivity

The frequency peak might be determined by a stimulus width which matches the receptive field center and reverses polarity at the same place the cell's sensitivity profile reverses polarity.

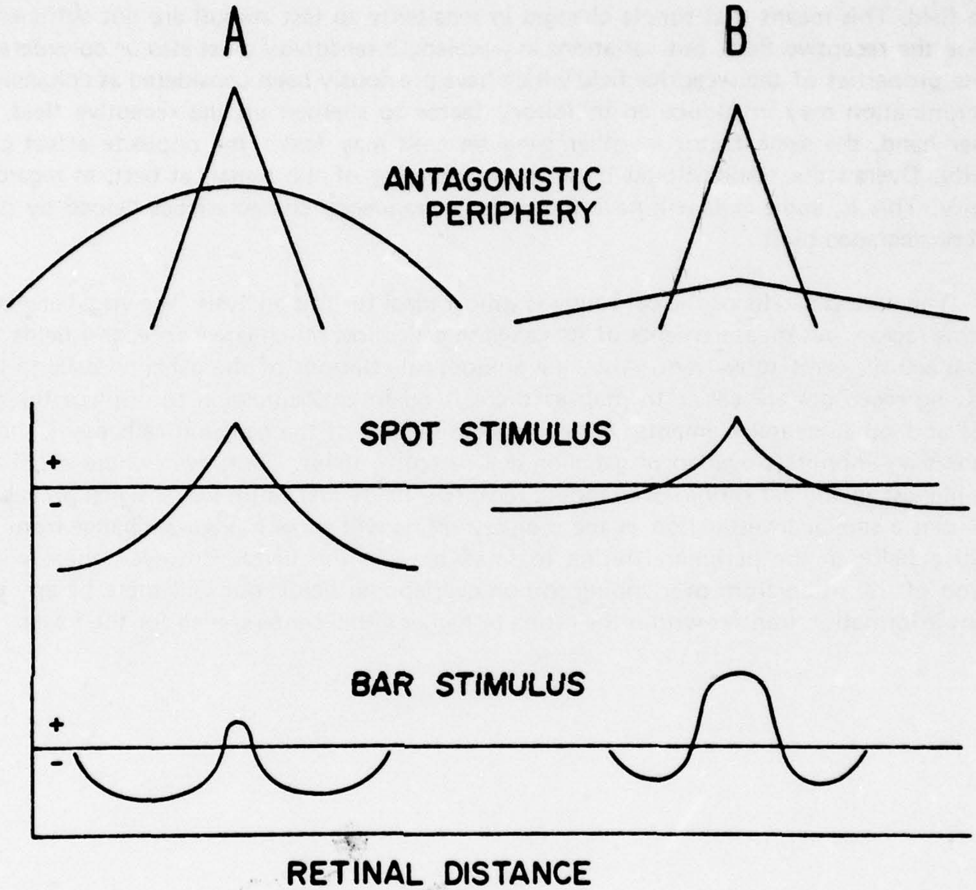

FIGURE 5

Central response to a Spot Stimulus

Even though the surround in A is stronger than in B, the change in the profile of the surround antagonism produces similar responses with stimulus integration over the large size of the point spread function.

An unexpected complication in matching the spatial distribution profile of the ganglion cell receptive field sensitivity changes with intensity related changes in visual acuity arises from the fact that the wavelength sensitivity of the response is location dependent within the receptive field. This means that simple changes in sensitivity to test stimuli are not sufficient to describe the receptive field, but variations in wavelength sensitivity must also be considered. Also, some properties of the receptive field which have previously been considered as enhancing color discrimination may introduce an inhibitory factor to sharpen up the receptive field. On the other hand, the same factor in other ganglion cells may foster the opposite effect on visual acuity. Overall the result should be an even smearing of the signal, at best, as regards visual acuity. This is, some cells will have their spatial frequency characteristics helped by it, others will be degraded by it.

The area centralis of the cat retina is almost ideal for this analysis. The visual acuity is high in this region, yet measurements of its ganglion cells show much larger receptive fields than the visual acuity seems to warrant. Also, the anatomical relations of the ganglion cells to their underlying receptors are easier to map as there is no foveal depression to displace the ganglion cells and other neural elements. A simple examination of the ganglion cells easily shows that there is an enormous overlap of ganglion cell receptive fields. Thus, even where visual acuity is the highest in the cat retina, overlapping receptive fields suffice for visual signal processing. We feel that a similar investigation in the monkey retina will show a gradual change from large receptive fields in the peripheral retina to small ones in the fovea. However, there will be no region of transition from overlapping to non-overlapping fields, nor will there be any point to point information transfer within the retina or higher visual centers, even for the fovea.

NOTES AND REFERENCES

1. The material in this report follows an analysis of the problem described by M. L. Wolbarsht/ J. R. Ringo in the final report for NASC Contract N00019-77-C-1033. "Visual Acuity and Retinal Organization" February, 1978. This report should be consulted for an amplification of many of the points raised in the present discussion.

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M. L. WOLBARSHT

DISCUSSION

A PARTICIPANT: Do you mean literally that the receptor density in the pigeon retina is everywhere as high as the receptor density in the human fovea?

DR. WOLBARSHT: No, not exactly, but the falloff is quite a bit different. The visual acuity throughout much of the pigeon retina is perhaps equally as good. But that doesn't mean that it's as good as the human. I think that the pigeon has probably at least a 20/20 acuity over perhaps an 80 degree cone. The pigeon has two foveas but they have nothing to do with visual acuity. They have the very sharp bi-convex type in which there is no displacement of the layers and if you take the fovea out it doesn't make any difference to visual acuity. Literally, the pigeon, if he has a small patch of the retina left does just about as well in a visual acuity measurement as if he had the whole retina, and you can take any patch you want.

DR. COHEN: The pigeons, as you recall, were trying to discriminate orange. Maybe we're looking too strongly on visual acuity. Maybe it's color-contrast sensitivity. And with the fact that the pigeon having more cones distributed throughout its retina, it's more sensitive to making these types of color discriminations, and perhaps acuity isn't really the critical parameter here.

DR. WOLBARSHT: Well, the cones do both color and visual acuity, so they're going to go together. It needs both, and there is some trade-off. I don't mean that you can do it that quickly. But the fact that it has cones and you're making color discrimination, means also its visual acuity is high.

DR. GINSBURG: If you can indeed remove part of the retina and it doesn't affect visual acuity, how does that reconcile with your argument that the receptors are responsible for the acuity?

DR. WOLBARSHT: What I said was if you remove the pigeon's fovea, not the man's fovea, it will not affect its overall visual acuity, which means that the fovea is not the highest point of visual acuity in the pigeon retina. The pigeon fovea is different from man's fovea.

DR. GINSBURG: Well, why don't I see my blind spot if I am seeing with my retina?

DR. WOLBARSHT: One, because you have both eyes open.

DR. GINSBURG: Well, I have one eye open now.

DR. WOLBARSHT: The second is that the brain largely ignores what it doesn't see. Your problem is that you're trapped in your attention span, except with difficulty, to a little patch of visual space about the size of the moon; in other words, where the fovea is. It's very difficult to investigate in any detail parts of visual space apart from the fovea, and it requires, generally speaking, a trained subject. What you really find out are large things in movement.

DR. GINSBURG: But the point is, there is a hole in your sampling space. If indeed your sampling plane is the sampling space that's relevant to perception, I would suggest you would

see it. It would bother you. People who have measured the band width characteristics at the retinal ganglion cell level, at the LGN, and then go up to the cortex, find you have very broad band filters at your receptor level. And you find one way of getting at "supercuity" is to look at cascading these broad band filters to give you very narrow band filters.

DR. WOLBARSHT: The point that we're making is that the retinal network is not a passive relay system in terms of getting information from the receptor to the cortex for visual acuity.

DR. GINSBURG: Okay. I though you were trying to make an argument that you were seeing with your retina, which I think both of us agree- -

EYE RESPONSES IN A VIRTUAL IMAGE DISPLAY ENVIRONMENT

Gloria Twine Chisum, Ph.D.

The virtual image displays used in aviation are of two general classes, the Head-up Displays (HUDs) and the Helmet Mounted Displays and Sights (HMD/S). In this discussion I will refer to the helmet mounted virtual image devices as helmet mounted displays for simplicity of expression, though the sights and displays are not completely interchangeable. A helmet mounted display device can be used to perform all of the functions of a sight, but the reverse is not true. In a helmet mounted sight which is a relatively simple device, fixed symbols which are either on or off are available. In a helmet mounted display, addressable devices such as cathode ray tubes (CRT) or diode arrays are used to generate the displayed images so that either the sight symbols or continuously variable information can be displayed. A Head-Up Display is a device which is mounted on the aircraft. (Figure 1) The crew member looks through the beam splitter, or combining glass, of the aircraft mounted device at the outside environment and simultaneously sees information such as landing information or some other type of information which is displayed. The device used to generate the images displayed is a CRT in a conventional HUD (Figure 2) or a deflected laser beam in a holographic HUD (Figure 3). In the holographic HUD the beam splitter is a hologram. A variety of symbols and information can be presented on these two devices because of the methods utilized to generate the images.

A helmet mounted device makes use of a helmet mounted beam splitter, usually the helmet visor, though other beam splitters may be used (Figures 4 and 5), an image generating device such as a helmet mounted projector, CRT or diode array, or an aircraft mounted image generator with fiber optics used to transfer the images from the generating device to the point at which the images are projected onto the beam splitter. (Figure 6) The HMDs make use of helmet position sensing devices so that the head position and line of sight can be used to control devices such as radar, cameras and other sensors (Figure 7) or to direct and display information from various sources such as video devices. (Figure 8)

There are certain obvious conditions which are present in an environment in which virtual image devices are used. From this point on, most of my remarks will be directed to HMDs though some pertain to HUDs as well. The information to be displayed to the user must be readable as the user views the environment outside the aircraft. In general, it will not be desirable to have the information displayed when the crew member looks inside the cockpit. There are exceptions to this general case, of course. Two exceptions are use of the HMDs in helicopters and in V/STOL type aircraft, when a pilot may want to know what is directly beneath the aircraft, and would cue the display system by looking down. One major advantage of a HMD is that it relieves a crew member of the necessity of frequent shifts of gaze in and out of the cockpit,

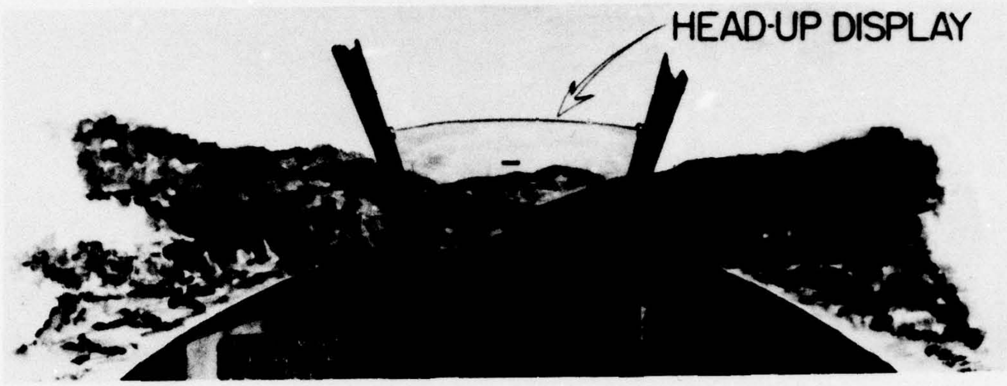

FIGURE 1. HEAD-UP DISPLAY

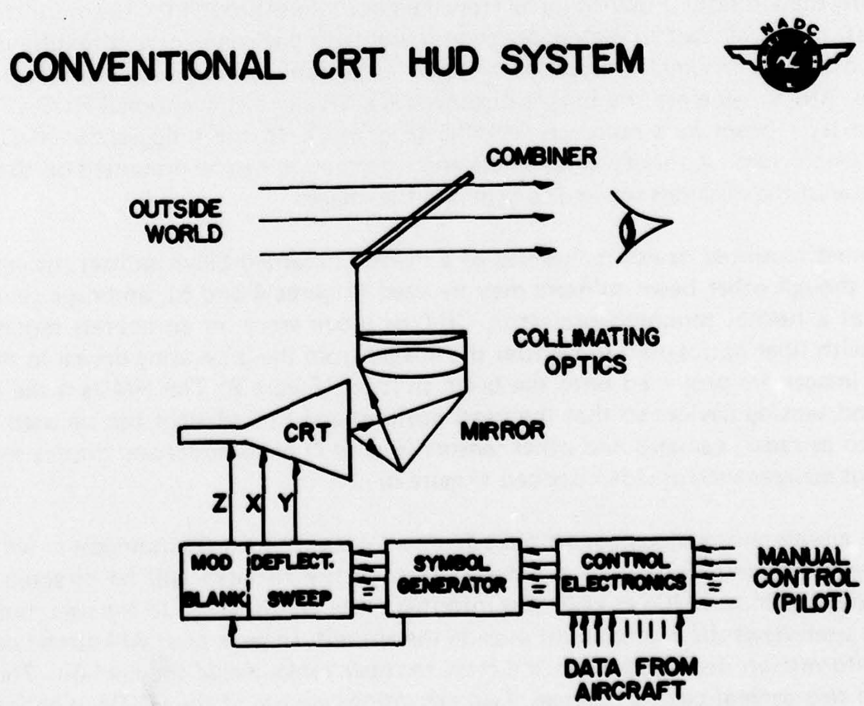

FIGURE 2. CONVENTIONAL HEAD-UP DISPLAY

LASER HUD SYSTEM

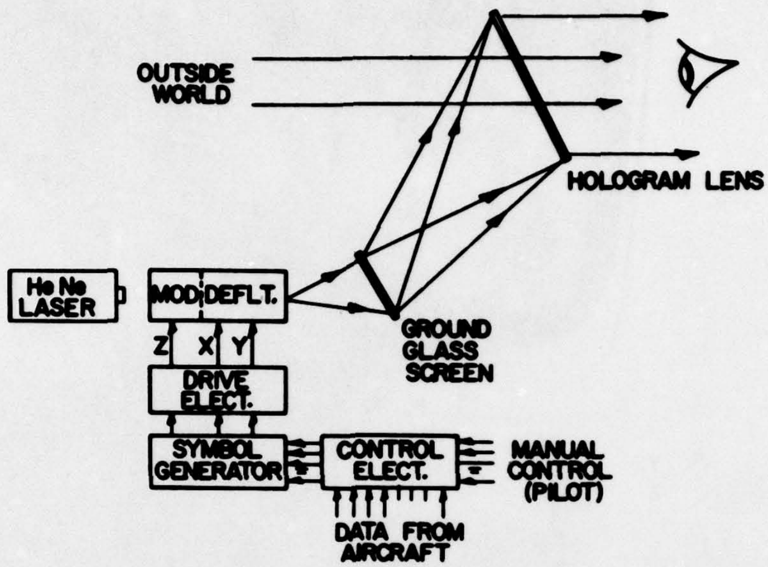

FIGURE 3. HOLOGRAPHIC HEAD-UP DISPLAY

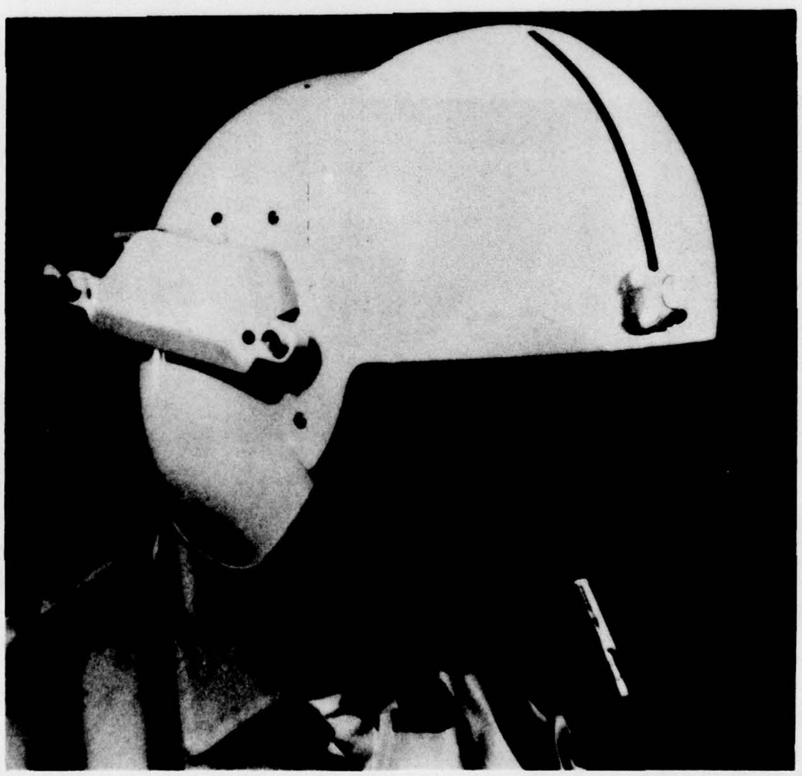

FIGURE 4. HELMET MOUNTED DISPLAY (VISOR BEAM SPLITTER)

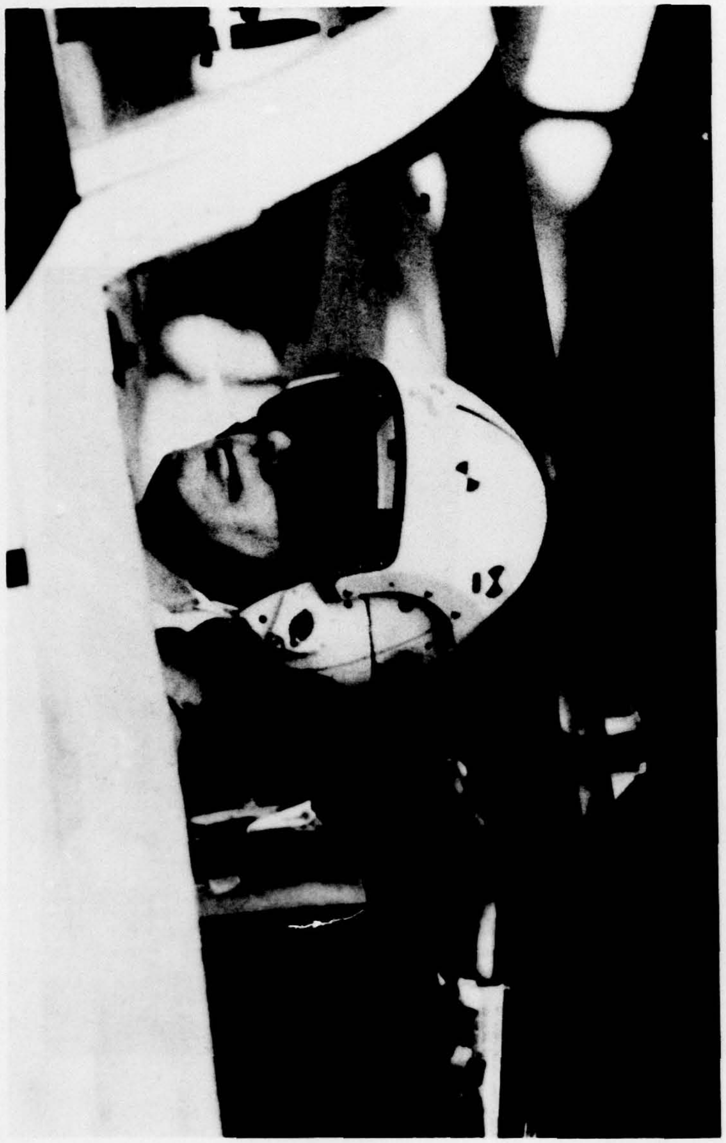

FIGURE 6. HELMET POSITION SENSING DEVICE

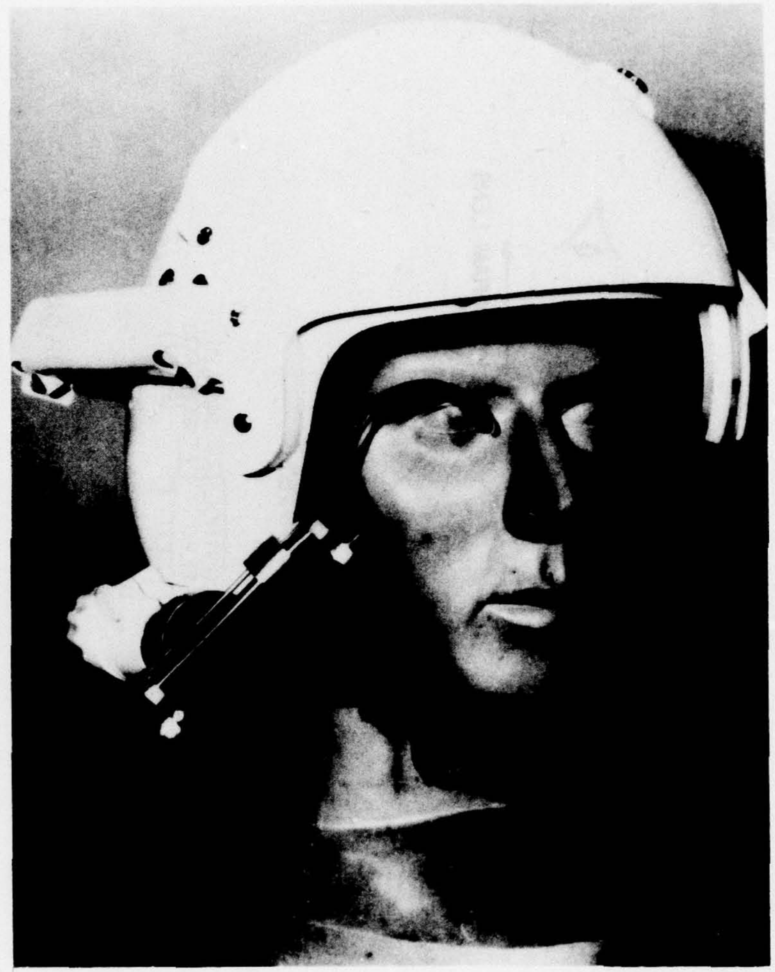

FIGURE 5. HELMET MOUNTED DISPLAY (DISCREET BEAM SPLITTER)

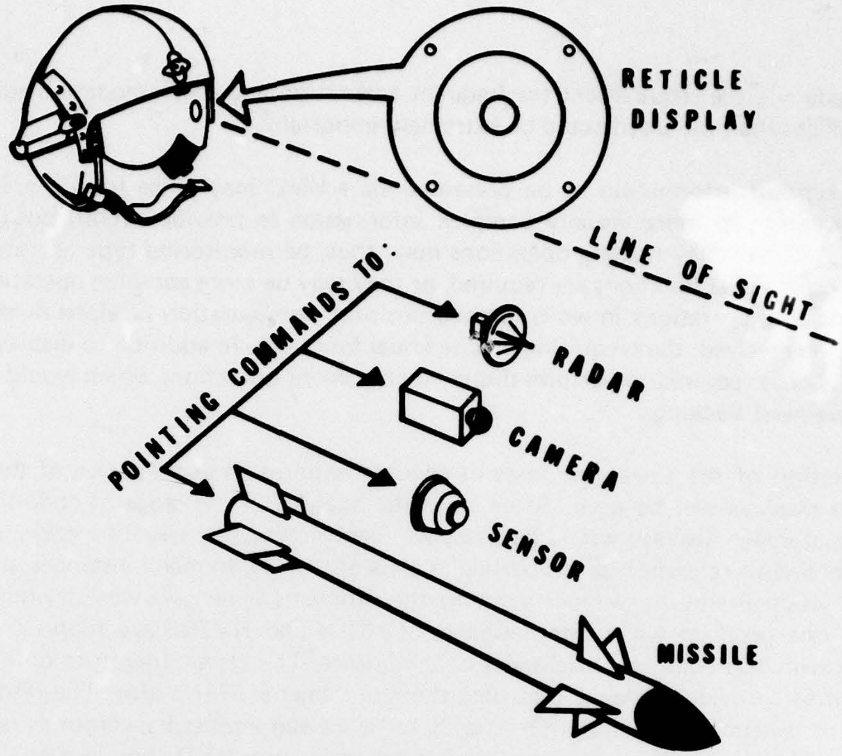

FIGURE 7. HELMET SIGHT

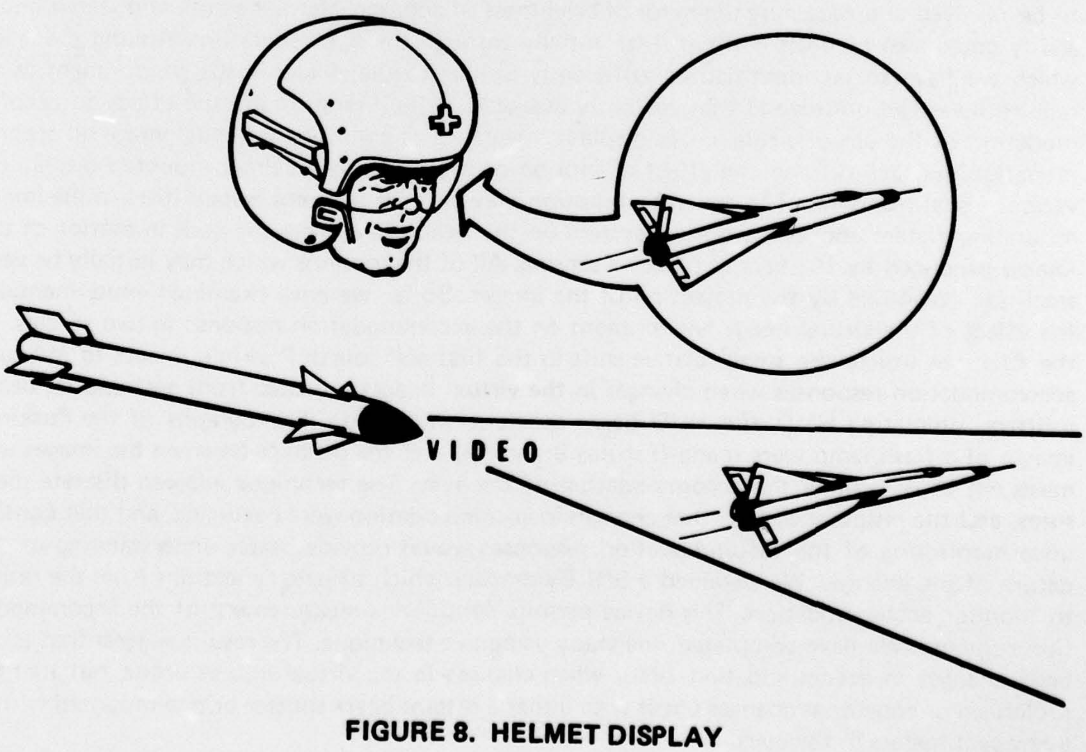

FIGURE 8. HELMET DISPLAY

thereby reducing the requirement for frequent adaptation and accommodation adjustments. In some instances the time saved could be extremely important.

The type of information to be presented via a HMD may range from simple signal light type information to more visually complex information to provide aircraft position and condition data. The display reading operations may, thus, be monitoring type operations in which relatively gross visual functions are required, or they may be more complex operations including accurate reading operations in which precise position, configuration or alpha numeric information must be resolved, thus requiring precise visual functions. In addition to display reading, the user may also be required to perform display management operations which would involve some form of eye-head tracking.

Definition of the visual responses of concern requires an examination of the situation in which the displays will be used. After an initial analysis of the range of conditions in which HMD virtual image displays would be used, we identified several visual functions which should be examined with reference to this particular class of devices. In many instances, information in the basic vision literature was pertinent to the problems which we were trying to solve. For example, one problem which the designers of HUDs and HMDs have found a great deal of difficulty with has been the brightness of the images. The classic literature on brightness and color contrast provide guidance regarding the requirements in this area. The resolution of the problem of generating beam splitter images to be viewed against backgrounds ranging from a bright daylight sky to a dark background is a bit easier in a HMD than in a HUD because the reflection/absorption characteristics of a visor beam splitter can be more freely manipulated than can those of a HUD beam splitter. The acuity capability of the eyes was another area in which the general literature provided guidance both in the consideration of achromatic images to be resolved and regarding the range of brightness of concern. Vernier acuity and stereoscopic acuity could also be dealt with, at least initially through the basic literature. Among the areas which we have so far identified as sufficiently unique to the virtual image environment as to require investigation beyond that currently available in the literature are the effect on accommodation of the use of virtual image displays, the effect of color of the virtual image on accommodation and acuity, and the effect of motion of the image in a helmet mounted display on various visual responses. The sources of motion may be from inherent instabilitites in the image generating system and in the optical system on the helmet and from the built in motion of the images produced by the helmet position sensing. All of the motions which may initially be very small are magnified by the projection of the images. So far we have examined experimentally the effect of the virtual image environment on the accommodation response in two studies. In the first, we utilize the small relative shift in the first and fourth Purkinje images to measure accommodation responses when changes in the virtual images reflected from near and far beam splitters, simulating HMD and HUD beam splitters, were made. Photographs of the Purkinje images of a flash lamp were made (Figures 9 and 10) and the distance between the images was measured to determine the accommodation of the eyes. The technique allowed discrete measures, and the results suggested that changes in accommodation were occurring, and that continuous monitoring of the accommodation responses would provide better understanding of the nature of the changes. We obtained a SRI Eyetracker which utilizes reflections from the retina to monitor accommodation. This device permits continuous measurement of the accommodation response. We have completed one study using this technique. The results suggest that small brief changes in accommodation occur when changes in the virtual images occur, but that no prolonged or consistent changes occur with either a distant beam splitter or one mounted within a few centimeters of the eyes.

FIGURE 9. PURKINJE IMAGE APPARATUS

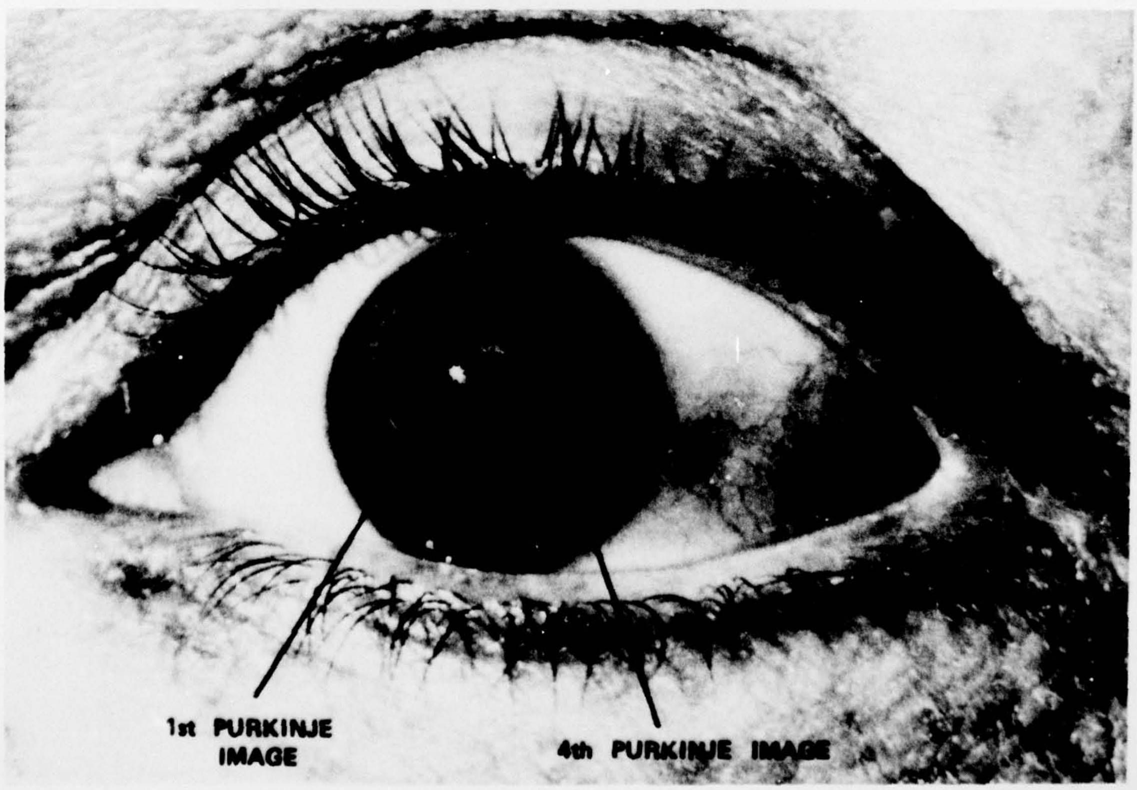

FIGURE 10. PURKINJE IMAGE PHOTOGRAPH

The response of the eyes to monochromatic or nearly monochromatic stimuli as might be produced by CRT phosphors, diode arrays and lasers will be investigated. The responses of concern will be the accommodation response and reading efficiency in prolonged exposures. We will also monitor eye movement during the performance of a variety of tasks while the virtual images are being presented.

Another area of concern which we plan to investigate is the effect of intentional and unintentional motion of the images such as that which results from the use of helmet tracking devices. The information from such a study will provide an indication of the compromises required in tuning or desensitizing the helmet position sensing devices.

GLORIA TWINE CHISUM, Ph.D.

DISCUSSION

DR. STARK: In spite of some of the literature by Fincham and by Campbell and Westheimer, I think it is now considered that the eye doesn't use chromatic fringes for accommodation. So, you should be able to accommodate very well with one chromatic light. ! think that's now accepted.

COL TREDICI: Do you have a problem? If there was one, the accommodation shift would show up in the end by having alterations in the vision, in the final chain of events so to speak. And if it doesn't, then it's obviously less than is practical to be concerned about.

DR. CHISUM: What we have currently in use are sights. In the sights we are generating a reticle which is not a very demanding task, or peripheral lights, which also are not very demanding tasks. We can tolerate a wide range of accommodations in that case without really degrading the use of the information. But now when we come to the point at which we want to produce sensor information we want to use these to display the kinds of information that Bill Mulley was talking about this morning, selectable by the pilot. We are now looking at more demanding visual tasks, and what we want to be sure of is that these sights which were satisfactory for very gross kinds of visual operations are in fact satisfactory for these more demanding kinds of visual operations, or whether we need to be concerned about building more stability into the system than we had with those. Initially, the lack of stability in the system for the sight was not thought to be a problem. What had to be done eventually was that the helmet had to be made more stable. The motion they got just from the movement of the helmet was too much to even permit use of the sight. Now that we are talking about a more demanding kind of task, the questions are: Do we have to go to even greater lengths to stabilize the images, stabilize the helmet? Can we tolerate some flexing in the visor? What will happen to these when we're putting holograms rather than a refracting reflector in the system?

These are the kinds of questions that we are trying to deal with before we get an operational system, and then we have to go back and start making after-the-fact kinds of corrections. We want to know whether we need to build this into this system initially.

COL TREDICI: As you will eventually use the sight, as I saw from those pictures, the sight is in the left eye? the right eye is looking unencumbered.

DR. CHISUM: But we are working on a binocular display.

DR. TREDICI: Well, when you get to the single one, you are probably going to bring out his phoria, depending on how dense this blocking is, in the eye that the image is on. Let's say its on the left eye. It will be acting as a mild Maddox rod which is like stresssing him- -you'll be doing a phoria test on him all the time, unless he can overcome that. Some will overcome and some you'll have to do selection.

DR. CHISUM: Well, even with the monocular one, we won't have differences in density. What we will have is differences in the light reaching the eye from a reflected image. But the density of the whole visor would be the same. Stereopsis is an added factor which we would

like to be able to provide for certain kinds of applications such as if we wanted to display a hot line gun sight. Then we may want to put depth information in it. And that would require just a very simple stereoscopic display.

Now, if we want to provide landing cues for a V/STOL type aircraft- -and this is what the V/STOL people are looking for - - we will definitely want to try to put the stereoscopic information in the display. But the binocular display, for a number of reasons, is certainly preferable to a monocular display.

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